

TRANSACTIONS
of the
American
Foundrymen's Association



Proceedings of the
FORTY-FIRST ANNUAL MEETING

Milwaukee, Wis.
May 3 to 7, 1937

VOLUME XLV

EDITED BY
R. E. KENNEDY and N. F. HINDLE

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of the
American Foundrymen's Association
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**Vice President*, Marshall Post, Birdsboro Steel Foundry & Machine Co., Birdsboro, Pa.
**Executive Vice President*, C. E. Hoyt.†
Secretary-Treasurer, D. M. Avey.†
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Director of Safety and Hygiene Section, E. O. Jones.†
Manager of Exhibits, C. E. Hoyt.†
Assistant Secretary-Treasurer, J. Reininga.†
Assistant Technical Secretary, N. F. Hindle.†

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*(In addition to the President, Vice President
and Executive Vice President)*

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Terms Expires 1939

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**J. L. Wick, Jr.*, Falcon Bronze Co., Youngstown, Ohio.

** Member of Executive Committee.*

† Association office, 222 W. Adams St., Chicago.

President's Annual Address

By JAS. L. WICK, JR.,* YOUNGSTOWN, O.

Members of the American Foundrymen's Association, Ladies and Gentlemen:

This is the Forty-First Annual Convention and Exhibition of the AMERICAN FOUNDRYMEN'S ASSOCIATION. We are representatives of one of the greatest and oldest industries of our country. In it, there is an investment of approximately one billion dollars. In it, there are 300,000 people working hand in hand. And I venture to guess that we will have registered at our convention before the week is ended at least 7,000 people.

While Milwaukee is one of the leading and most progressive foundry centers of the United States, your Board of Directors, in selecting it, gave recognition to the progressive Milwaukee Chapter, for it is this chapter that is the real power behind this convention. We, of the official family, are conversant with their splendid work and we present our thanks and congratulations. But, because of the long sustained and continued interest and activity of these men in this community in all the problems of our industry, it is not surprising that since 1935, when they were organized into a chapter, their accomplishments have been so outstanding. So when your supplemental communication signed by your complete chapter Board of Directors urged the timeliness and advantage of a convention with an exhibit, we were assured of your enthusiastic cooperation.

We are happy that you are the second chapter of the American Foundrymen's Association to entertain us. We are impressed with the program on which we are about to embark. It will not only benefit those participating directly in it but it will reflect with credit the service that the A.F.A. offers our entire membership.

We have come to this gathering for various reasons. To many, it offers the opportunity for renewing acquaintanceship with former friends, members and officers, thus preserving a continuing association with those who have had a long and varied experience with certain aspects of our great industry.

To my mind, this is the grand and glorious characteristic of

* President, Falcon Bronze Co.

the AMERICAN FOUNDRYMEN'S ASSOCIATION, this continuity of interest indefinitely sustained by the older members, — these men who have had the resources and ability to discover new facts and improve old processes and who have been willing to share their knowledge with those not so fortunate, conscious of the fact that they advance only as the entire industry advances. These, with their long and varied experience, serve to introduce to us younger members the tasks that lie ahead. They divert our attention from the specific details of the immediate problems to a long-range discussion of general policies, in an atmosphere highly charged with wide experience and wise counsel.

Many of us are here with a questioning, searching curiosity, with an inquiring mind, for the very definite purpose of listening, possibly taking part in and contributing to the discussion of some problem or practice, the solution of which would help us in the problem back home.

Many of us are here on the road to Damascus. We have not seen the light and we hope to meet someone who has traveled further along this road, who will open our eyes that we may see.

Many of us have come here because we realize that man is a tool-using animal. Without tools, he is nothing. With tools, he is everything. Giving this word "tools" its widest meaning, it is tools that man's progress depends upon, his continuous advancement in the application and use of equipment and materials.

This Convention offers what I call a service department in the truest sense. There are here over 200 exhibitors who, at great cost of time, effort and expense, have brought together a wide variety of products and equipment most essential in the successful production of castings. This is especially true at this time, with our industry operating at an unusually high rate and at the same time faced with a serious shortage of skilled mechanics. These exhibitors feature these new developments and refinements in equipment and supplies which have been most recently perfected. They will gladly demonstrate these at your convenience, and their chief concern is to help you to put the right tool in the right place, having in mind their immediate and ultimate purpose.

Many of us are here seeking some specialized knowledge which will assist us in choosing and applying these tools to our business. We are about ready to be sold; we are potential buyers. We are willing to try them and we are just trying to decide on the right material and the right equipment for the right place. We are here to be shown, but we are not going to be stampeded into buy-

ing. We will listen to demonstrations but we are going to keep our eyes open as we go through plants and see where they are installed.

Many of us are here to listen to and possibly meet those outstanding members of our industry who have made great contributions to its advancement.

Many of us are here attending our first Convention. Perhaps you are a little shy—feel as though you are just on the fringe. But, as someone has said, "Remember the dearest friends you now have were once strangers to you." That foundryman at your elbow does not have to belong to your private collection of acquaintances before you speak to him. Most foundrymen, whatever their jobs, are interesting and friendly. You will find them just as eager to know you as you are to know them.

If this is your first Convention, I ask you to stop for just a moment and consider that one goes to the American Foundrymen's Association Convention and Exposition for the first time just once. You will never forget certain preliminaries, but many of the things that you have made this trip on purpose to see and hear, things that you vow you will never forget, you will forget, unless you do a little work.

You say you consider this a vacation; you are here for pleasure. Let me tell you that your pleasure will be greater and will last longer if you make a few notes on what you see and hear. I would suggest you provide yourself with a notebook. You older members will remember at the last International Convention how those foreign delegates filled their notebooks. Consider yourself as covering this Convention for your associates back home. Check the equipment with that which you have at home. Compare it with the same type on exhibition here. Remember, the educational process is not complete until the impression has been followed by expression. You cannot remember that funny story until you have passed it on to someone else. The old Quaker said, "What I give away, I take with me."

While you are here, work. Such notes as you will make, you will find valuable. Their helpfulness increases. They will never pass into nothingness but will still keep your memory bright.

Your president serves you by cooperation with your board of directors and your executive officers, your staff, and your enthusiastic committeemen—a group of living men meeting living needs. Never have I known or worked with a group whose personnel was of a higher character or whose members were so con-

scientiously devoting their time and their best thought and effort to the interests of this Association.

I have been impressed with the close relationship between the foundrymen and the equipment men. Each seems to feel that they advance only as the other advances. The foundryman wants the equipment man to advance so he can advance, and the equipment man wants the foundryman to advance, so we can all go together.

This Association renders a continuously enlarging service and grows thereby, because the men who are interested in it are growing. Such associations do not persist without devotion, and close association with superlative ability, personality and character provides the deepest and the most effective sort of stimulæ.

I think it was the late Charles Vickers, as you remember, who used to come to all our Conventions, and who said to me one time, "One can't live long enough to know all there is to know in the foundry business," and I think he limited it to my own subdivision, the non-ferrous section.

I remember down on Cape Cod one day an old fisherman telling me the haddock was sort of an offspring of a contact the fish had had with the devil. I said, "Gee! I never knew that before." The old man pointed his finger at me and he said, "Young man, I want you to understand that it takes all the people in all the world to know all there is to be known."

I ask you to think that over for just a moment, some of you who are so self-satisfied with what you are doing in your own plants. There is hardly a man in the ranks of the foundry industry from whom we cannot learn. All our bright ideas are not our own. The success we have had has been due to those about us and to those whom we meet under circumstances such as this, who make available to us the results of their own research and experiments and experience.

Let us continue to stimulate our activity in our great industry with interesting conventions and exhibits and by broader chapter activities. We must meet and get management into this; we must have the support of all of industry, from management down to the apprentice. Let us press definitely on along the road that leads to improvement in our product. Let us provide better than just ordinary working places for our men. Let us pay the highest possible wages. Let us hope for encouragement on the part of our government which will result in a further revival of our business activities.

We must provide the opportunity for the beginner, through intelligent direction, to increase his knowledge by active participation in a progressive educational experience. Call it apprenticeship training, cooperative education or just a chance, vocational training, or whatnot.

Milwaukee, as you have heard, has pioneered in this activity. Apprenticeship training is well exemplified here. We must continue this propaganda of the past, sponsored and led by such able men as Harold Falk, C. J. Freund, J. C. Davis, and many others. Let us carry on every effort to convince the industry of the desirability of training young men for the essential trades that constitute our basic industry.

Cooperative community effort sponsored by the local chapters must be launched, because many of our foundries are entirely too small to establish apprenticeship training on an individual basis. You have in this program and in the *TRANSACTIONS* of previous conventions all that is necessary to inaugurate such a cooperative project in your own industry.

I welcome you to this Convention and to the opportunity that it offers for progress through imitation, study and emulation of the superior qualities close at hand.

Report of Executive Vice-President, Annual Meeting, Board of Directors

CHICAGO, JULY 20, 1937.

Members of the Board of Directors, American Foundrymen's Association:

From the several reports that will be presented today, you will learn of the activities of the past year and plans for the coming year. As a background for considering these reports, a brief review of past history may be helpful.

Organized in 1896, the Association was incorporated, not for profit, under the laws of Illinois in 1916. In that year the Association took over the handling of exhibits which were organized and handled by the Foundry Supply Manufacturers' Association from 1906 to 1910 inclusive, and by the Foundry and Machine Exhibition Company from 1911 to 1915 inclusive.

The Association had no funds for handling exhibits and the initial cost and necessary expense was underwritten by two past Presidents, both deceased, Joseph S. Seaman, President in 1900 and Major Joseph T. Speer, President, 1911-1912. R. A. Bull was President and A. O. Backert, Secretary-Treasurer. The officers and members of the Executive Committee engaged me to manage the Association's first exhibit which was held in Cleveland, September, 1916. Miss Reininga, now our Assistant Secretary, was my stenographer.

At the convention in Milwaukee, October, 1918, A. O. Backert was elected President and I was elected Secretary-Treasurer and Manager of Exhibits. Shortly thereafter the office of the Association was moved from Cleveland to Chicago. There was not much to move—one oak case for filing preprints and a few letter files. The Association's total assets, including cash, was less than \$1,000.

In 1921, Technical Secretary R. E. Kennedy, then Instructor at the University of Illinois, was engaged as Assistant Secretary. He carried on his work at the University until 1928 when he moved to Chicago. Up until that time we had only a two room office, with sometimes one and sometimes two stenographers beside Miss Reininga. In 1934, N. F. Hindle was made Assistant Technical Secretary and in January, 1936, E. O. Jones came to us as Director of Safety and Hygiene. Then, on January 1, last, I became Executive Vice President and Dan M. Avey came with us as Secretary-Treasurer. The above constitute our full-time working staff. We have at present six stenographers.

From our two-room office in 1928 we have expanded and now have a general office, six private offices, all well equipped, stock rooms and file rooms.

We have had some lean years since 1930. In 1932, the year we cancelled our plans for a Philadelphia show, we found ourselves in the red to the amount of \$23,606. We operated in the red during 1933 and 1934.

When our books were audited in June, 1935, we were again in the black but only to the amount of \$376.30. Today you will learn from the reports of the Finance Committee and the Treasurer that we are well out of the red. The audit will show assets amounting to \$59,927.55, exclusive of award fund investments totalling \$21,520 and an award fund interest account of \$2,873.13.

Our membership also suffered severe losses during those lean years, dropping to a low of 1205 at the close of the year, June, 1934. Our membership as of June 30, last, was 2355, an increase of nearly 100 per cent over 1934.

During the past year, we have frequently been told that A.F.A. was at the "crossroads". Today, largely because of the work of President Wick's Fact Finding Committee under the able guidance of Chairman Frank Lanahan whose report you will hear, we feel that we are well out on the highway, all hitched up and ready to go places.

We have mentioned our staff, set-up and assets, but one of our greatest assets is our Official Family, consisting of past officers and directors, always loyal and interested as evidenced by the way they turn out for the annual gatherings. We challenge any national association to equal the record established in 1934 when 14 out of 19 living past Presidents attended the Alumni meeting.

This continued interest can be attributed in part to the hold we retain on our Past Presidents. For instance, when President Wick turns the gavel over to President-elect Bornstein today, he will automatically become Chairman of the Finance Committee, Chairman of the Board of Awards, consisting of the seven last living Presidents, and will be, for three years, a member of the Nominating Committee. As a past President he will also be a member of the Advisory Board for Life, and, following precedent, will continue on the new board, having been elected as a Director for a three year term.

It has been a great privilege and pleasure to work with the Boards of Directors of A.F.A. year after year. On each such occasion as this, some Directors graduate to the Official Family, constituting an ever increasing group of staunch supporters of A.F.A. As they retire, we will welcome new members to the board to take their places. For a longer time than any of those present, I have had the thrill of observing this always interesting drama on the stage of A.F.A.

In closing, I desire to bring to you on behalf of our entire staff, greetings and appreciation for your helpful cooperation during the past year.

Respectfully submitted,

C. E. HOYT, *Executive Vice President.*

Report of Secretary-Treasurer, Annual Meeting, Board of Directors

CHICAGO, JULY 20, 1937.

Members of the Board of Directors, American Foundrymen's Association:

We submit herewith a brief report covering Membership, Finance, Publications and Safety and Hygiene Work, which will be supplemented by more detailed reports during the session.

Membership

The total membership, according to an analysis of June 30, 1937, shows 2355, a gain for the year of 341 or 17 per cent. It will be recalled that on June 30, 1936, the total membership was 2014 which gave an increase of 48 per cent over 1935. In the Secretary's report of that date, credit was given to the stimulus of chapter activities and general improvement in business conditions with the active help of two conventions within the fiscal year.

Pending decision as to membership classification and dues structure, no planned drive for members has been made during the past six months. However, individual solicitation and the work of chapters has been effective in the degree reflected by the figures given.

In anticipation of a reclassification, individual letters were addressed to each Limited Firm member inviting such member to convert to General Firm classification. Approximately 25 per cent of the July 1 invoices have been paid and of the Limited Firms addressed, more than 20 have elected to change to General Firm classification.

An analysis of the membership structure and the total listing of members affiliated with chapters has been prepared by Miss Reininga. This report is in the hands of each Director and will be given further consideration by Mr. Hoyt in his discussion of membership and dues.

Finances

Following the close of the fiscal year, a detailed analysis of receipts and disbursements was prepared and, by authorization of President Wick, an audit was made by Robert T. Pritchard, C.P.A.

In 1937, according to the auditor's analysis, the excess of income over expenses is \$14,217.28. The total assets of the Association including cash, accounts receivable, inventory of publications, investments at cost and exclusive of award funds for the past fiscal year is shown as \$59,927.35.

An analysis of award fund securities in 1936 showed investments with a par value of \$21,000 worth, at that time, \$22,834. In 1937 the award fund investments had a market value of \$22,476.75.

During the year appropriations were authorized and expenditures made to cover three gold medals with bronze replicas; cash prizes to apprentice contest winners totalling \$320.00 and the preparation and engrossing of certificates for medal and apprentice prize awards. Authorization will be asked at this meeting for the appropriation of the sum

of \$30.00 to cover special prize for a theme contest at the Milwaukee convention.

In addition, by reason of the lower price obtainable and the trend in the gold market, an additional medal was purchased and is held available for next year's awards. So far as possible, funds were drawn from each of the four donor accounts to maintain a balance and the award certificates expense was assigned to surplus/interest fund.

Chapters

During the past two years, two new chapters were organized, bringing the total to eleven. The Southern California Chapter was admitted on petition to the Board during the annual meeting in Milwaukee. A petition from the Buffalo Chapter received too late for action in May will be presented at this meeting. Preliminary work in several other sections doubtless will produce other chapters during the coming year. Totals of membership in various chapters is shown in the accompanying analysis which was previously mentioned.

Publications

No sweeping change was made in the character of publications during the past year. The Bulletin and Transactions still is presented on the bi-monthly basis. This and other technical publications are reviewed by the Technical Secretary in his report.

One change in policy relating to republication was made. This change retains to the A.F.A. the right of determining by definite release such papers and reports as are issued for reprinting. The reaction from commercial publications has indicated increased interest in such republication and a broader use of the free privilege of abstract.

The number of special sessions devoted to management, as will be shown by the Technical Secretary's report, has given rise to presenting such papers and proceedings as a management series in advance of their appearance in Transactions. A controlled method of distribution by pre-prints available in advance of the regular Transactions is expected to stimulate acceptance and use of these special management reports.

Safety and Hygiene

During the past year, valuable assistance has been rendered by the Safety and Hygiene Section in occupational disease legislation. Working with members in respective states, assistance has been given in Indiana and Michigan in furthering fair occupational disease laws. The Illinois insurance group continues as a laboratory or testing ground for ascertaining facts relating to insurance, coverage, administration and rates. Further, the A.F.A. has given assistance through working with the National Rating Board and with foundry interests in Wisconsin in securing marked reductions in premiums. This broad service has been supplemented by individual consulting work in the improvement of plant housekeeping; advising on the medical and insurance matters. A more detailed report by Mr. Jones will give a clear insight into this valuable work.

Respectfully submitted,

D. M. AVEY, *Secretary-Treasurer.*

Report of Manager of Exhibits, Annual Meeting Board of Directors

CHICAGO, JULY 20, 1937.

Members of the Board of Directors, American Foundrymen's Association:

In submitting to you the report of the exhibit staged in Milwaukee Auditorium, May 3 to 7, 1937, we are prompted to incorporate into the report, that we may have it as a permanent record, our letter of October 12, 1936, announcing to exhibitors our 1937 program. This letter addressed to exhibitors at the annual convention in Detroit in '36 with copies to our entire exhibitor prospect list read as follows:

"When we said goodbye to you or to your representatives on the closing day of the exhibit at Detroit, it was quite generally understood that our 1937 convention would be held without an exhibit.

"Invitations for the 1937 convention were received from cities as far east as Baltimore and New York and as far west as St. Louis and Milwaukee. At the annual meeting of the Board of Directors, July 23, these invitations were referred to the Executive Committee for further consideration and recommendations for a letter ballot of the Board of Directors.

"The Executive Committee met in Chicago, September 20, at which time they considered, in addition to the formal invitations that had been filed, a supplementary communication from the Milwaukee Chapter of A.F.A. signed by the 11 members of the Board, all executives of leading foundries of that city, urging the timeliness and advantages of a convention with an exhibit and offering the facilities of Milwaukee Auditorium in which was held the 1918 and 1924 conventions and exhibits of the Association.

"The importance of the foundry industry in the Milwaukee district, the assured cooperation of officers and members of the Milwaukee Chapter and the fact that the 1934 convention was held in Philadelphia, 1935 in Toronto and the 1936 in Detroit were all factors in deciding the Executive Committee to unanimously recommend that the 1937 convention with an exhibit be held in Milwaukee.

"This recommendation has now been approved by letter ballot of the Directors and in a publicity release dated October 15, announcement will be made of the selection of Milwaukee. Shortly thereafter you will, as prospective exhibitors, receive detailed information about this event. In the meantime, may we suggest that you mark the dates May 3 to 7 on your 1937 calendar and consider making provision in your next year's budget for an exhibit that week."

Regardless of the fact that our exhibitors generally had understood that there would be no exhibit in 1937, the announcement was well re-

ceived, due largely to the attractions of Milwaukee as a foundry center, improved business conditions and the fresh memory of a successful convention and exhibit in Detroit the previous May.

Milwaukee Auditorium had limitations as to total space available but the most serious obstacle was the limited head room in Mechanics Hall where operating exhibits were located. In spite, however, of limitations and restrictions, the Milwaukee exhibit should be recorded as one of the most successful ever staged both as to quality of exhibits and attractiveness of displays.

The total number of exhibitors at Milwaukee exclusive of educational or non-commercial exhibits was 212 as against 214 at Detroit in 1936. Total space sold was 50,732 as against 55,714 at Detroit.

Following the convention we received many letters from exhibitors with more than the usual number of expressions of satisfaction with results obtained.

While it is gratifying to learn that companies participating were well satisfied, it is even more gratifying to realize that in staging a convention with an exhibit in Milwaukee, having an attendance four or five times greater than we would have had without an exhibit, the benefits to the foundry industry generally were such as to fully justify the action of the Board of Directors in approving the recommendations of the Executive Committee for 1937.

We desire to once more go on record as opposed to opening exhibits on Monday. From the report of the Manager of Exhibits a year ago, we quote as follows:

"There are many objections to opening on Monday, requiring as it does overtime installation labor costs from Saturday noon until Monday morning.

"I am strongly of the opinion that the most satisfactory schedule of dates we have ever had was on the three occasions when we opened exhibits at noon Saturday, continuing through until 10 p. m., closed Sunday and opened again Monday morning.

"This Saturday opening serves as a sort of dress rehearsal and gives the exhibitors an opportunity to rearrange or make adjustments on Sunday, get rested and be ready for the crowd when the convention starts on Monday."

Overtime for installation work now includes all day Saturday and Sunday.

Our last Saturday opening was in Cleveland in 1923. Our experience was that aside from the saving of expense in the installation of exhibits and the advantage of being completely ready when the convention opened on Monday morning, we had the further advantage of securing local publicity, definitely helpful in building attendance at the meetings and exhibits during the following week.

Salesmen who covered the Milwaukee territory following the convention advised that many foundry executives expressed to them disappointment at not having an opportunity to see more of the exhibits for the reason that they were kept at their plants to receive visitors during convention week.

A Saturday opening would provide an opportunity for local foundry-

men to spend several hours at the exhibits which they would otherwise be deprived of. For all these reasons, we strongly favor a Saturday opening for the exhibit, closed on Sunday and the convention opening Monday.

Respectfully submitted,

C. E. HOYT, *Manager of Exhibits.*

Report of Technical Secretary

Annual Meeting, Board of Directors

CHICAGO, JULY 20, 1937.

To the Board of Directors, American Foundrymen's Association:

Your Technical Department has this past year functioned chiefly along the following lines: (1) Preparation of program for the 41st Annual Convention, with committees formulating the program for the various sessions; (2) editing and publication of Bimonthly Transactions and Bound Volume of Proceedings No. 44 (1936); (3) Committee work, and (4) Regional meetings.

Convention Sessions and Papers and Reports

It is believed that the 41st Annual Convention program stands as a record in extent of interest and quality of papers. In addition to the formal opening meeting and the annual business meeting, 28 sessions were held, three of these being round table conferences and five shop operation course sessions. Of these 28 sessions, six were listed for the first time under a Management Section. Forty-six papers and thirteen committee reports in all were presented. These will be later published together with their discussions as our annual volume of Transactions No. 45.

Engineering Instructors Dinner

Instructors from ten universities and three technical high schools and two vocational schools attended the annual engineering instructors dinner of the Milwaukee convention. In addition, there were present members of the A.F.A. Committee on Cooperation with Engineering Schools Research. This meeting, as an annual affair is, we believe, doing much to promote interest in foundry research and instruction on the part of the instructors in engineering schools and it is our recommendation that it be continued as a part of our annual program.

Shop Instructional Courses

The Shop Course of five sessions this year was a combination of gray iron foundry and sand shop courses. The interest and attendance continued as it has been manifested in past years. All who have been instrumental in putting on these courses, recommend their continuance and extension.

Round Table Luncheons

Round table luncheon conferences were held by the Steel, Malleable and Non-ferrous Divisions this year. The non-ferrous conference was outstanding due to the attention paid to its preparation.

Publications

The publications issued during the year were:

Regular:

- Vol. 44—Transactions (688 pages).
- Bimonthly Transactions (6 issues).
380 pages bulletin items.
736 pages convention papers, reports and discussions.

Special:

- Standards of Four-Year Foundry Apprenticeship.
- Reprint of Safety and Hygiene Session 1936 Convention.
- Preprints (29) of Papers for Milwaukee Convention.
- Code for Grinding, Polishing and Buffing Sanitation.
- Code for Testing and Measuring Air Flow in Exhaust Systems.
- Recommended Practice for Sand Cast Magnesium Alloys.
- Present Status of Foundry Sand Investigation and Control.
- The Field of Malleable Cast Iron.

Digests of Current Foundry Literature

During the year 37 pages of digests of current foundry literature have been published in the bulletin section of the bimonthly Transactions. It is our recommendation that this digest service be continued in the belief that members, who do not have other index services, may be stimulated to use this reference material, as it is this class of membership which should be educated to look up existing information on their current foundry problems.

Cast Metals Handbook

The Policy Committee on the Cast Metals Handbook, at its meeting May 5, decided that the second edition should be prepared and issued in the spring of 1938. Committees of each division have been organized to direct the revisions of the various sections.

In addition to supplying members with copies of the first edition, copies have been sold to engineers and in quantities to groups for lecture courses, and to engineering schools for class work.

Regional Two-Day Foundry Conferences

The office has this past year cooperated in holding four regional conferences. These were:

University of Iowa. This was a two-day meeting held in cooperation with the Quad City Chapter, the Northern Iowa Foundrymen's Association and the University of Iowa, at Iowa City, October 30-31. Attendance, approximately 150 from Iowa, Illinois, Missouri and Minnesota.

Michigan State College. The Fifth Annual Sectional Conference at East Lansing, Michigan, was held April 9-10, under the auspices of the Michigan State College, the Detroit Chapter and the A.F.A. The attendance was approximately 100.

Birmingham. The Fifth Annual Birmingham Foundry Conference, sponsored jointly by the Birmingham Chapter and the Birmingham Section of the A.S.M.E. was held February 25-26. The attendance of approximately 500 was the largest for this series of meetings. This meeting has brought together engineers and foundrymen of the district, and is now the outstanding foundry meeting of the South.

Massachusetts Institute of Technology. The first two-day foundry conference of New England was held this year on April 9-10 at M. I. T., sponsored jointly by the Institute, the A.F.A. and the New England Foundrymen's Association. The program arranged by the committee under the chairmanship of R. F. Harrington, was organized to appeal to the engineer, as it featured casting design, and to the foundrymen. The attendance was 400, and the meeting was considered very successful.

Regional Meetings for 1937-38

At the present time six regional meetings are definitely in prospect for the 1937-38 season, these being: the Sixth Birmingham Conference, the Sixth Michigan State Conference, the Second Iowa Conference, and meetings at Battelle Memorial Institute, Columbus, O., Missouri School of Mines (in cooperation with the St. Louis Chapter), and Cornell University at Ithaca, N. Y. The Battelle meeting is proposed as a strictly technical foundry meeting, to specialize on some few outstanding foundry metallurgical problems.

International Relations Committee

The International Relations Committee, under the chairmanship of Frank G. Steinebach, this past year has had only nominal functions, as no major International Congress was held. Mr. Steinebach has forwarded cablegrams of greetings to the various European meetings and worked with our office in selecting authors of exchange papers.

Our Association has been honored this year by having our European representative, Vincent Delport, elected as president of the International Foundry Committee. He presided in this capacity at the European Congress, held in France in June.

Exchange Papers

A.F.A. exchange papers for European meetings were prepared by O. W. Ellis, Toronto Research Foundation, and W. Paul Eddy, General Motors Truck Corp. The I.B.F. exchange paper before our Milwaukee meeting was prepared by J. Roxburgh, who covered in a very interesting manner the production of heavy castings. These papers bring to 83, the number which have been presented in this exchange arrangement.

Foundry Cost Committee

The Cost Committee, under the chairmanship of Director Sam Tour, has functioned this year by developing an excellent convention session to discuss the cost systems of the various branches of the industry. Malleable, gray iron and non-ferrous cost methods were presented. The report of this session is to be issued as one of the management series of reprints.

The Gray Iron Founders' Society, the Malleable Founders' Society and the Steel Founders' Society are now officially represented on our Cost Committee, and there is every reason to expect from this committee, activities of value to the executives of the industry.

Apprentice Training Committee

The Apprentice Training Committee, this past year, has been one of our most active committees. It has been instrumental in having several chapters hold apprentice training meetings. For the 41st Annual Convention, it organized two sessions, the first time this has been done. Further, it conducted the annual molding and pattern making contests, with entries in steel, gray iron and non-ferrous molding and pattern making classes, with three prizes in each class being awarded. The prizes consisted of cash awards of \$40, \$25 and \$15 for first, second and third places, respectively, and were furnished through the Board of Awards.

The committee contemplates for 1938 the same general program and, in addition, is reviewing for revision and republication the Standards for Four-Year Foundry Apprenticeship. Also, it proposes to maintain a special section in the bimonthly bulletin.

Foundry Sand Research

The Foundry Sand Research Committee has continued under the leadership of Dr. H. Ries, technical director. There are eleven sub-committees studying such phases as test methods, rebonding clays, durability, grading, purchase forms and high temperature effects.

Research

The Board, at its meeting a year ago, approved funds for research work on the effects of high temperatures on sands, to be carried on at Cornell University. This project was started late in the fall, with a research associate, H. L. York, working under the direction of Dr. Ries and Professor Davis of Cornell, and the committee (R. E. Aptekar, H. D. Phillips, W. Finster, D. L. Parker and D. C. Zuege). The program called for the investigation of steel sands and their properties as the first phase of the work. No report has been submitted for this work as yet, but it is scheduled for the 1938 meeting.

COOPERATION WITH OTHER ASSOCIATIONS

Representation on A.S.T.M. Committees

The Association has continued its policy of cooperating with the American Society for Testing Materials, recognizing the A.S.T.M. as the organization for the development of specifications and standards for engineering materials. There are thirteen A.F.A. representatives on A.S.T.M. committees, which are dealing with subjects of interest to foundrymen.

American Standards Association

The A.F.A. is represented on fifteen committees functioning under the procedure of the American Standards Association.

International Committee on Testing Cast Iron

Our representative, W. H. Spencer, on the International Committee for Testing Cast Iron, reports that a review of test methods of the various

countries has been distributed to each member organization. Other activities started are a study of classification of graphite size, the preparation of an international foundry dictionary and a study of casting defects.

A. F. A. DIVISIONS

Gray Iron Division (Chairman, Jas. T. MacKenzie)

The principal work of the Gray Iron Division this past year has been, *first*, the preparation of the Milwaukee program, and *secondly*, the preparation of a comprehensive report on Alloy Cast Iron. This report is scheduled for final review this fall and publication before the 1938 convention.

The Committees on Fluidity Testing, Cooperation with Engineering Schools Research, and Shop Operation Courses, have also been quite active. The Committee on Cooperation with Engineering Schools Research has made a survey of research facilities and of needed projects, making recommendations to several schools of projects which were deemed most important. The Fluidity Test Committee has been enlarged by the appointment of representatives from the Steel, Malleable and Non-Ferrous Divisions, in reality making this a general interest committee.

Steel Division (Chairman, Paul E. McKinney)

The Steel Division has made much progress this past year in committee activities, and four sessions at the Milwaukee Convention were largely devoted to the discussion of the seven committee reports presented. These committees with their chairmen were:

- (1) Specifications (E. W. Camplon).
- (2) Methods of Producing Steel for Castings (F. A. Melmoth).
- (3) Test Coupons (J. M. Sampson).
- (4) Heat Treatment (A. N. Conarroe).
- (5) Radiography (C. W. Briggs).
- (6) Casting Design (R. A. Bull).
- (7) Steel Foundry Sands (R. E. Aptekar).

The reports of six of these committees will be printed as part of the proceedings. The seventh, that on Casting Design, prepared by Major Bull, will be issued as a special publication, with the objective of placing it in the hands of users and designing engineers.

The Division is planning on making these committee reports an important part of their annual sessions.

Non-Ferrous Division (Chairman, H. M. St. John)

The Non-Ferrous Division is continuing to function satisfactorily under the supervision of its advisory committee.

The Division had at Milwaukee a very good program of two papers sessions and a round table meeting. The round table meeting has been reported as unusually successful due to the preparation of the committee under the supervision of C. V. Nass.

A new committee was appointed to work with the Sand Research

Committee, and as a result the first session on non-ferrous sand control was held at Milwaukee.

The Committee on Recommended Practices, having issued and published recommendations on aluminum alloys and magnesium alloys, has this past year been revising practices covering: Sand Cast High Lead Bronze, Brass and Valve Bronze, Manganese Bronze. These three are scheduled for completion this year, while others are proposed.

The Committee on Recommended Procedure for Analysis of Defects has reported that its final report should be available for publication this year.

Malleable Division (Chairman, R. J. Teetor)

The Malleable Division has this past year had five active committees—those on (a) Program and Papers; (b) Round Table Conference; (c) Specifications; (d) Handbook Revision, and (e) Malleable Shrinkage Study.

The Program Committee organized two sessions for the Milwaukee convention, while the Round Table Conference Committee developed the annual conference for the Milwaukee convention. The Specifications Committee has cooperated with the A.S.T.M. Committee on Malleable Iron in formulating a specification for pearlitic malleable iron. This specification was considered at the meeting of the A.S.T.M. Committee A-7 last month, and was referred back to the sub-committee.

A study of malleable iron shrinkage was started last fall. A special pattern was made and shipped to ten foundries making irons of different carbon analysis. The castings and test bars made have been shipped to a central point for examination, and the complete report will be made at the 1938 convention.

Respectfully submitted,

R. E. KENNEDY, *Technical Secretary.*

Summary of Proceedings of the 41st Annual Meeting

THE Forty-First Annual Convention of the AMERICAN FOUNDRYMEN'S ASSOCIATION was held in Milwaukee, Wis., May 3 to 7, 1937. In conjunction with the convention, the Association held a major Foundry Show where exhibits of foundry equipment and supplies which occupied all the exhibit halls of the Milwaukee Auditorium were displayed. There were 212 firms represented, displaying many new features in attractively arranged booths.

The registered attendance, 8,000, approached closely the record attendance of predepression conventions. The point in evidence throughout the convention was the fact that the sessions covering a large variety of subjects were as well or better attended than any previous annual meeting. The large number of papers and the volume of recorded discussions presented and recorded in this volume of TRANSACTIONS attests the great interest the foundry industry is taking in all phases of technical and practical developments.

For the first time in the history of the Association, a complete series of sessions of primary interest to management was held, the sessions covering safety, apprentice and foreman training, occupational disease laws, foundry costs and job evaluation, and time-motion study. The proceedings of these management sessions have since been published as special reprints Nos. 37-30, 37-31, 37-32 and 37-33.

Eleven technical sessions were held on gray iron, steel, malleable and non-ferrous subjects. In addition there were five shop operation course sessions and three round table conferences.

The Stag Dinner on Tuesday evening, May 4, taxed the capacity of the Hotel Schroeder, there being over 1,200 present, the largest single gathering of foundrymen ever held in this country.

Over 600 members and guests attended the Annual Dinner, the program including the presentation of the John A. Penton, William H. McFadden and J. H. Whiting Medals to John W. Bolton, C. W. Briggs and Dr. Jas. T. MacKenzie, respectively.

The Milwaukee convention committee as organized by the Milwaukee Chapter is to be congratulated on the excellent manner

in which it assisted in staging the convention details of reception, plant visitation and ladies entertainment. To the Milwaukee Chapter convention committee, and especially those who served as chairmen and vice-chairmen, the Association gratefully acknowledges its indebtedness for the splendid arrangements planned and executed in making this convention an outstanding success.

A summary of the various sessions follows:

OPENING SESSION

Monday, May 3, 2:00 P. M.

Presiding: James L. Wick, Jr., President, American Foundrymen's Association.

President Wick, after declaring the 41st Annual Convention formally opened, presented Wm. F. Bornfleth, chairman of the Milwaukee Chapter, A.F.A., who, in the name of the chapter as host to the convention, welcomed the members of the Association and guests to Milwaukee. Following this, President Wick introduced the Honorable Daniel W. Hoan, mayor of Milwaukee, who welcomed the Association by an address in which he pictured the importance of Milwaukee in the foundry and general manufacturing industries.

Vice-President Hyman Bornstein, on behalf of the Association, responded to these two addresses of welcome.

Frank G. Steinebach, chairman of the International Relations Committee, next read a cablegram of greetings from the Institute of British Foundrymen. This read:

"The Institute of British Foundrymen sends cordial greetings to the American Foundrymen's Association, best wishes for industrial prosperity and a successful convention."

Signed, J. E. HURST, President

TOM MAKEMSON, Secretary

Mr. Steinebach then presented the following motion:

"That the International Relations Committee be instructed to send a cablegram to the Institute of British Foundrymen, accepting and thanking them for these greetings, and extending to the I.B.F. the very best wishes of the American Foundrymen's Association for the success of the I.B.F. convention which takes place in June of this year."

The motion was duly seconded by Dr. J. T. MacKenzie and approved by a unanimous vote.

At this point President Wick requested Vice-President Bornstein to assume the chair. Chairman Bornstein then announced the appointment of a committee to present in nomination the names of four members, two together with the last three immediate past presidents would constitute the Nominating Committee for 1938. Those appointed on this committee were:

W. B. Crawford, Atlas Foundry Co., Detroit, Mich.

J. H. Redhead, Lake City Malleable Iron Co., Cleveland, Ohio.

W. J. Laird, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

Then the personnel of a Committee on Resolutions was announced as:

A. E. Hageboeck, Frank Foundries Corp., Moline, Ill., Chairman.

Frank J. Lanahan, Fort Pitt Malleable Iron Co., Pittsburgh, Pa.

Following these announcements, the chairman presented President James L. Wick, Jr., who gave the annual presidential address. This address appears on pages v to ix.

The meeting was then adjourned.

SHOP OPERATION COURSE (Session 1)

Monday, May 3, 4:00 P. M.

Chairman—P. T. Bancroft, Moline, Ill.

D. J. Reese, International Nickel Co., Bayonne, N. J., presented a discussion on "*Cupola Construction and Operation*."

J. A. Bowers, American Cast Iron Pipe Co., Birmingham, Ala., presented a paper on "*Capacity of Cupola Basins*."

SHOP OPERATION COURSE (Session 2)

Tuesday, May 4, 8:30 A. M.

Chairman—R. K. Akin, Chicago Malleable Castings Co., Chicago.

H. A. Deane, Deere & Co., Moline, Ill., acted as discussion leader, the subject being "*Synthetic Foundry Sands*."

GRAY CAST IRON

Tuesday, May 4, 10:00 A. M.

Chairman—H. Bornstein, Deere & Co., Moline, Ill.

The following papers and report were presented and discussed:

Ferrite, Its Occurrence and Control in Gray Cast Iron, by Richard Bancroft, Perfect Circle Co., New Castle, Ind., and A. H. Dierker, Ohio State University, Columbus, O. This paper was presented by Mr. Dierker.

Effect of Coke Size on Cupola Melting, by J. A. Bowers and Dr. J. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.

Pressure Castings, H. H. Judson, Goulds Pumps, Inc., Seneca Falls, N. Y.

Report of Committee on Fluidity Testing, presented by Committee Chairman W. H. Spencer, Sealed Power Corp., Muskegon, Mich.

STEEL CASTINGS

Tuesday, May 4, 10:00 A. M.

Chairman—H. D. Phillips, Dodge Steel Co., Philadelphia, Pa.

The following papers and reports were presented and discussed:

Designing for Steel Castings, by R. A. Bull, Chicago, Ill.

Report of Committee on Methods for Producing Steel for Castings, by F. A. Melmoth, Detroit Steel Castings Co., Detroit, Mich.

Specifications for Steel Castings, by E. W. Campion, Bonney-Floyd Co., Columbus, O., Steel Division representative on A.S.T.M. Committee A-1 on Steel.

Studies on Solidification and Contraction in Steel Castings V—Contraction Stresses, by C. W. Briggs, Naval Research Laboratory, Washington, D. C. This paper was presented by title only.

Report of Committee on Coupon Tests, by J. M. Sampson, General Electric Co., Schenectady, N. Y.

MANAGEMENT—JOB EVALUATION AND TIME-MOTION STUDY

Tuesday, May 4, 10:00 A. M.

Chairman—H. S. Washburn, The Plainville Casting Co., Plainville, Conn.

The following papers were presented and discussed:

Job Evaluation for Rate Setting, by Bertram Miller, General Electric Co., Erie, Pa.

Time-Motion Study and Job Standardization, by H. C. Robson, Link-Belt Co., Chicago, Ill.

The proceedings of this session appear in A.F.A. reprint 37-32.

GRAY CAST IRON

Tuesday, May 4, 2:00 P. M.

Chairman—Dr. J. T. Mackenzie, American Cast Iron Pipe Co., Birmingham, Ala.

Vice-Chairman—G. P. Phillips, International Harvester Co., Chicago, Ill.

The following papers were presented and discussed:

High Strength Cupola Iron Practice, by R. S. MacPherran, Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Hardenability of Cast Iron, by D. W. Murphy and W. P. Wood, University of Michigan, Ann Arbor, Mich. This paper was presented by Mr. Murphy.

Cast Iron for Nitriding, by J. E. Hurst, Staffordshire, England. In the absence of the author, this paper was presented by J. W. Kleier, Allis-Chalmers Mfg. Co., Milwaukee, Wis.

STEEL CASTINGS

Tuesday, May 4, 2:00 P. M.

Chairman—R. A. Bull, Chicago, Ill.

In opening the session, the chairman presented a resolution reflecting the attitude of the Steel Division of the Association on the death of George Batty, a director of the Association and member of the Steel Division Executive Committee. This resolution was adopted unanimously, and it was moved that a copy be transmitted to the widow, and recorded in the archives of the Association.

The resolution as presented by Major Bull was as follows:

**Resolution on the Death of George Batty, Adopted by the
Steel Division of the American Foundrymen's Association**

In the death of George Batty, which occurred in March 1937, the American Foundrymen's Association lost one of its former Directors who had achieved a very high reputation among many producers and consumers of steel castings. The deceased was an Englishman by birth, an American by adoption, and an internationally recognized asset to the steel casting industry throughout the world.

George Batty's connection with this Association began in April 1928, and was maintained actively until his death. He served the A.F.A. not only as a Director for a three-year period, but as a highly valued member of many technical committees, and as author of several papers of exceptional merit, published in the Transactions of this Association.

Because of the many helpful contributions made by George Batty for advancing the steel casting industry, the members of the Steel Division of the American Foundrymen's Association experience a feeling of personal loss in the termination of their friend's career. Those who became well-acquainted with the deceased were deeply impressed by the alertness of his mind; the concentrated, intelligent study given by him to founding problems; and the sincerity, earnestness, and energy that characterized the man. For the reasons stated above,

BE IT RESOLVED by the members of the Steel Division of the American Foundrymen's Association in regular session assembled on this, the fourth day of May, 1937, that an appropriate tribute be paid to the memory of George Batty by means of this Resolution which shall be permanently filed in the records of the Association; and that a copy of this Resolution be transmitted as an expression of deep sympathy to Mrs. Batty, who has been left to mourn the departure of her companion, but who may be comforted in some degree by realizing the great esteem in which her husband was held by his colleagues in the steel casting industry.

AMERICAN FOUNDRYMEN'S ASSOCIATION.

C. E. HOYT,

Executive Vice-President.

DAN M. AVEY,

Secretary-Treasurer.

The following reports were then presented and discussed:

Radiography and Steel Castings—Committee Report, presented by C. W. Briggs, Naval Research Laboratories, Anacostia, Washington, D. C., committee chairman. Mr. Briggs was assisted in the presentation by the following members of his committee:

E. J. Ash, University of Michigan, Ann Arbor, Mich.

R. E. Gezelius, Naval Research Laboratories, Anacostia, Washington, D. C.

L. D. Christie, Jr., American Manganese Steel Co., Chicago Heights, Ill.

L. C. Wilson, Reading Steel Casting Co., Division of American Chain & Cable Co., Reading, Pa.

The other report was that on *Heat Treatment of Steel Castings*. In the absence of Chairman A. N. Connaroe, National Malleable & Steel Casting Co., Chicago, Ill., the report was presented by committee member D. C. Zuege, Siver Steel Casting Co., Milwaukee, Wis.

MALLEABLE CAST IRON

Tuesday, May 4, 2:00 P. M.

Chairman—P. C. DeBruyne, Moline Malleable Iron Co., St. Charles, Ill.

Co-Chairman—E. A. Gullberg, Deere & Co., Moline, Ill.

The following paper and committee report were presented and discussed:

Shrinkage in Malleable Cast Iron—Committee Report, presented by J. H. Lansing, Malleable Founders Society, Cleveland, O.

Physical Tests of Heat Treated and Fully Annealed Malleable Irons, by R. Schneidewind and A. E. White, University of Michigan, Ann Arbor, Mich. This paper was presented by Mr. Schneidewind.

SHOP OPERATION COURSE (Session 3)

Tuesday, May 4, 4:00 P. M.

Chairman—K. H. Priestley, Eaton-Erb Foundry Co., Vassar, Mich.

At this session a discussion on *Cupola Operation and Carbon Control* was lead by Fred J. Walls, International Nickel Co., New York, N. Y.

APPRENTICE TRAINING

Wednesday, May 5, 10:00 A. M.

Chairman—John H. Ploehn, French & Hecht, Inc., Davenport, Iowa.

Vice-Chairmen—H. C. Van Cleaf and W. E. Watson, Allis-Chalmers Mfg. Co., Milwaukee, Wis.

The following papers were presented and discussed:

Apprentice Training for Foundries, by Macon P. Miller, Lynchburg Foundry Co., Lynchburg, Va.

Apprentice Training—Plan of Caterpillar Tractor Co., by K. P. Crowell, Caterpillar Tractor Co., Peoria, Ill. In the absence of the author, Mr. Crowell's paper was presented by B. B. Wittfoht, apprentice instructor, Caterpillar Tractor Co., Peoria, Ill.

Apprentice Training as Viewed by a Graduate Apprentice, by Carl F. Haertel, Falk Corp., Milwaukee, Wis.

The proceedings of this session appear in A.F.A. reprint 37-31.

SAND RESEARCH

Wednesday, May 5, 10:00 A. M.

Chairman—H. B. Hanley, American Laundry Machinery Co., Rochester, N. Y.

The following papers and committee report were presented and discussed:

Durability of Foundry Sands, by C. E. Schubert, University of Illinois, Urbana, Ill.

Control of Core Hardness, by H. W. Dietert and Earl Woodliff, H. W. Dietert Co., Detroit, Mich. This paper was presented by Mr. Dietert.

Report of Committee on Sand Research. This was presented by Dr. H. Ries, technical director of the committee, Cornell University, Ithaca, N. Y.

MALLEABLE FOUNDING

Wednesday, May 5, 10:00 A. M.

Chairman—L. N. Shannon, Stockham Pipe Fittings Co., Birmingham, Ala.

The following papers were presented and discussed:

Selection of Annealing Cycles and Furnaces for Annealing Malleable Cast Iron, by A. F. Landa, Central Scientific Institute for Machine Production, Moscow, U.S.S.R. In the absence of the author, this paper was presented in abstract form by Carl F. Joseph, Saginaw Malleable Iron Co., Saginaw, Mich.

Sand Control in a Malleable Foundry, by E. C. Zirzow, National Malleable & Steel Castings Co., Cleveland, Ohio.

Developments in Melting Malleable Cast Iron, by W. R. Bean, Whiting Corp., Harvey, Ill.

MALLEABLE DIVISION LUNCHEON AND ROUND TABLE CONFERENCE

Wednesday, May 5, 12:30 P. M.

Chairman—E. P. Meyer, Chain Belt Co., Milwaukee, Wis.

This Round Table Luncheon conference was given over to the review of *Newer Annealing Methods*, informal reviews of the various newer types of annealing methods being given by those in attendance.

STEEL DIVISION LUNCHEON AND ROUND TABLE CONFERENCE

Wednesday, May 5, 12:30 P. M.

Chairman—R. C. Woodward, Bucyrus-Erie Co., South Milwaukee, Wis.

Vice-Chairman—A. H. Jameson, Malleable Iron Fittings Co., Branford, Conn.

This Round Table Luncheon discussion was given over largely to a *Survey of the Report of the Iron & Steel Institute Committee on Steel Castings Research*. The survey was presented by C. W. Briggs, Naval Research Laboratory, Washington, D. C.

MANAGEMENT—FOUNDRY COSTS

Wednesday, May 5, 2:00 P. M.

Chairman—Sam Tour, Lucius Pitkin, Inc., New York, N. Y.

The cost methods of the Malleable, Gray Iron and Non-Ferrous industries were presented and discussed as follows:

Malleable Foundry Cost Methods, by R. E. Belt, Malleable Founders Society, Cleveland, Ohio.

Gray Iron Foundry Cost Methods, by W. J. Grede, Liberty Foundry Inc., Milwaukee, Wis.

Non-Ferrous Foundry Cost Methods, by J. L. Wick, Jr., Falcon Bronze Co., Youngstown, Ohio.

The proceedings of this session appear in A.F.A. reprint 37-33 and in this volume, pp. 705 to 752.

GRAY CAST IRON

Wednesday, May 5, 2:00 P. M.

Chairman—S. C. Massari, Association of Manufacturers of Chilled Car Wheels, Chicago, Ill.

Co-Chairman—Fred J. Walls, International Nickel Co., New York, N. Y.

The following papers were presented and discussed:

Wear Testing, by P. S. Lane, American Hammered Piston Ring Div., Koppers Co., Baltimore, Md.

Microstructure and Physical Properties of Cast Iron, by A. L. Boegehold, General Motors Corp., and V. A. Crosby, Climax-Molybdenum Co., Detroit, Mich.

An Improved Method of Making Test Bars, by A. I. Krynitsky and C. M. Saeger, Jr., National Bureau of Standards, Washington, D. C. This paper was presented by Mr. Saeger.

SHOP OPERATION COURSE (Session 4)

Wednesday, May 5, 4:00 P. M.

Chairman—E. J. Carmody, National Superior Co., Springfield, Ohio.

The subject for discussion at this session was *Core Making*. H. L. Campbell, American Hoist & Derrick Co., St. Paul, Minn., opened the meeting with comments on this subject, which was then discussed.

MANAGEMENT—SAFETY METHODS AND GOOD HOUSEKEEPING

Wednesday, May 5, 7:30 P. M.

Chairman—H. A. Nelson, Director of Workman's Compensation, Industrial Commission of Wisconsin, Madison, Wis.

The following papers were presented:

Foot and Leg Protection, by M. Walter Dundore, Beloit Iron Works, Beloit, Wis.

Eye and Respiratory Protection, by J. Holzbog, Chain Belt Co., Milwaukee, Wis.

A Consideration of Human Silicosis, by Dr. Norbert Enzer, Milwaukee, Wis.

Good Housekeeping, by Dr. E. G. Meiter, Employers Mutual Liability Insurance Co., Wausau, Wis.

Safety as Affected by Maintenance, by James Thomson, Continental Roll & Steel Foundry, East Chicago, Ind.

The proceedings of this session appear in A.F.A. reprint 37-30.

STEEL FOUNDING

Thursday, May 6, 10:00 A. M.

Chairman—John Howe Hall, Taylor Wharton Iron & Steel Co., High Bridge, N. J.

The following papers and committee report were presented and discussed:

Cement as a Bonding Material, by C. A. Menzel, Portland Cement Association, Chicago, Ill.

Sand Control as Related to Steel Casting Production, by Charles Fuerst, Falk Corp., Milwaukee, Wis.

Report of Committee on Steel Foundry Sands, by R. E. Aptekar, American Brake Shoe and Foundry Co., New York, N. Y.

NON-FERROUS FOUNDRY PRACTICE

Thursday, May 6, 10:00 A. M.

Chairman—H. M. St. John, Detroit Lubricator Co., Detroit, Mich.

Vice-Chairman—W. J. Laird, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

The following papers on sand control were presented and discussed:

Practical Applications of Sand Control in Non-Ferrous Foundries, by A. C. Arbogast, Northern Indiana Brass Co., Elkhart, Ind.

Some Fundamentals in Non-Ferrous Sand Control, by G. K. Eggleston, Detroit Lubricator Co., Detroit, Mich.

A Study of Non-Ferrous Sands, by H. W. Dietert and Earl Woodliff, H. W. Dietert Co., Detroit, Mich. Mr. Dietert presented this paper.

At this time there was convened the regular annual Non-Ferrous Division Business Meeting. Division Chairman H. M. St. John presided and reviewed the activities of the various division committees.

MANAGEMENT—OCCUPATIONAL DISEASE LAWS

Thursday, May 6, 10:00 A. M.

Chairman—D. M. Avey, American Foundrymen's Association.

The following papers were presented and discussed:

Occupational Disease Laws, by O. E. Mount, American Steel Foundries, Chicago, Ill. In absence of the author, E. O. Jones, American Foundrymen's Association, presented this paper.

Industrial Codes and Their Applications, by James R. Allan, International Harvester Co., Chicago, Ill.

The proceedings of this session appear in A.F.A. reprint 37-30.

NON-FERROUS DIVISION LUNCHEON AND ROUND TABLE CONFERENCE

Thursday, May 6, 2:00 P. M.

Chairman—C. V. Nass, Fairbanks-Morse Co., Beloit, Wis.

The Committee on Arrangements for this conference had secured castings illustrating various types of defects, causes and remedies, and these castings which were on display were discussed.

MANAGEMENT—FOREMAN AND APPRENTICE TRAINING

Thursday, May 6, 2:00 P. M.

Chairman—V. J. Hydar, Falk Corp., Milwaukee, Wis.

Vice-Chairman—S. M. Brah, International Correspondence Schools, Chicago, Ill.

At this meeting a paper on *Foreman Training* was presented by A. D. Lynch, J. I. Case Co., Racine, Wis. Following the presentation of this paper, Dr. Stewart Scrimshaw, Professor of Economics and Industrial Relations, Marquette University, and H. A. Frommelt, Head of the Mechanical Engineering Department, Marquette University, reviewed the various phases of *Apprentice Training and Labor Problems*.

The chairman presented various prepared questions which were further reviewed by the two discussion leaders.

The proceedings of this session appear in A.F.A. reprint 37-31.

REFRACTORIES

Thursday, May 6, 2:00 P. M.

Chairman—John Lowe, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

Vice-Chairman—A. H. Dierker, Ohio State University, Columbus, Ohio.

The following papers and committee report were presented and discussed:

Insulating Refractory Brick, Their Properties and Application, by A. V. Leun, Bethlehem Steel Co., Bethlehem, Pa.

Insulating Refractories, by Dr. G. A. Bole, Ohio State University, Columbus, Ohio.

Firestone as a Refractory, by Harry Rayner, Chrysler Corp., Detroit, Mich.

Report of Work of Joint Committee on Foundry Refractories, by E. J. Carmody, National Superior Co., Springfield, Ohio.

ANNUAL BUSINESS MEETING

Thursday, May 6, 1937, 4:00 P. M.

Presiding, President James L. Wick, Jr.

On calling the meeting to order, President Wick announced as the first order of business, the report of the Nominating Committee to be presented by the committee chairman, Past-President Frank J. Lanahan. The report was as follows:

"Nominations made by your committee are—

For President to Serve for One Year:

Hyman Bornstein, Deere & Co., Moline, Ill.

For Vice-President to Serve for One Year:

Marshall Post, Birdsboro Steel Foundry & Machine Co.,
Birdsboro, Pa.

For Directors to Serve Three Years Each:

Duncan P. Forbes, Gunito Corp., Rockford, Ill.

C. J. P. Hoehn, Enterprise Foundry Co., San Francisco, Cal.

Henry B. Hanley, American Laundry Machinery Co., Rochester, N. Y.

Thomas Kaveny, Herman Pneumatic Machine Co., Pittsburgh, Pa.

For Director to Serve Two Years:

C. E. Sims, Battelle Memorial Institute, Columbus, Ohio."

Respectfully submitted,

1937 NOMINATING COMMITTEE.

Past-President Frank J. Lanahan, Fort Pitt Malleable Iron Co., Pittsburgh, Pa., *Chairman.*

Past-President E. H. Ballard, General Electric Co., West Lynn, Mass.

Past-President T. S. Hammond, Whiting Corp., Harvey, Ill.

Garnet P. Phillips, International Harvester Co., Chicago, Ill.

Richard Schneidewind, University of Michigan, Ann Arbor, Mich.

John H. Locke, General Steel Castings Co., Eddystone, Pa.

Harold J. Roast, Canadian Bronze Co., Ltd., Montreal, Canada.

Mr. Lanahan moved "that the report of the Nominating Committee be accepted and that the Secretary be instructed to cast the unanimous ballot of the Association in favor of the nominees".

Being duly seconded, the motion was approved and President Wick declared the above named candidates elected to the offices named. He then introduced President-Elect Bornstein, requesting him to assume the chair.

At this time, Secretary D. M. Avey presented a recommendation of the Board of Directors that the following be elected to Honorary Life membership:

Retiring-President James L. Wick, Jr., Falcon Bronze Co., Youngstown, Ohio.

1937 Penton Medallist, John Ward Bolton, Lunkenheimer Co., Cincinnati, Ohio.

1937 McFadden Medallist, Charles Willers Briggs, Naval Research Laboratory, Washington, D. C.

1937 Whiting Medallist, James Tucker MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.

Mr. Avey moved that the recommendation be adopted. This motion, seconded by E. H. Ballard was, on being put to vote, unanimously approved.

President Wick then resumed the chair and called for the report of the committee appointed to nominate for election four members to serve on the 1938 Nominating Committee. This report was presented by the Committee Chairman W. B. Crawford, Atlas Foundry Co., Detroit, and recommended the following as nominees and alternates:

K. V. Wheeler, Lebanon Steel Foundry, Lebanon, Pa.;

Alternate: J. C. Pendleton, Newport News Shipbuilding & Drydock Co., Newport News, Va.

W. H. Doerfner, Saginaw Malleable Iron Co., Saginaw, Mich.;

Alternate: L. J. Wise, Chicago Malleable Casting Co., Chicago, Ill.

W. M. Ball, Jr., Edna Brass Mfg. Co., Cincinnati, Ohio;

Alternate: Charles E. Schley, Philadelphia Bronze & Brass Corp., Philadelphia, Pa.

R. R. Deas, Jr., American Cast Iron Pipe Co., Birmingham, Ala.;

Alternate: Harry J. Winters, J. S. McCormick Co., Philadelphia, Pa.

The report was signed by the committee members:

W. B. Crawford, Atlas Foundry Co., Detroit, *Chairman*.

Wm. J. Laird, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Walton L. Woody, National Malleable & Steel Castings Co., Cleveland, Ohio.

A motion to approve this report was made, seconded and carried.

R. E. Kennedy, Technical Secretary, on being called upon to announce the winners in the apprentice contests, reported as follows:

Steel Molding

Recommended for prizes in Steel Molding Contest:

First Prize, Stanley Raskiewicz, Sivyer Steel Casting Co., Milwaukee, Wis.

Second Prize, Kazmir Paliwoda, Cleveland Trade School, Cleveland, Ohio.

Third Prize, John Kelly, Maynard Steel Casting Co., Milwaukee.

Judges:

F. A. Pritzlaff, Falk Corp., Milwaukee.

John Weidephiel, Wehr Steel Co., Milwaukee.

Chas. St. Clair, Sivyer Steel Casting Co., Milwaukee.

Non-Ferrous Molding

Recommended for prizes in Non-Ferrous Molding Contest:

First Prize, John Elko, Allis-Chalmers Mfg. Co., West Allis, Wis.

Second Prize, Casimir Kotowicz, Ampeco Metal Corp., Milwaukee.

Third Prize, Mike Kost, Cleveland Trade School, Cleveland, Ohio.

Judges:

Adolph H. Schott, Standard Brass Works, Milwaukee.
A. H. Passman, Loeffelholz Co., Milwaukee.
Geo. Klink, Allis-Chalmers Mfg. Co., West Allis, Wis.

Gray Iron Molding

Recommended for prizes in Gray Iron Molding Contest:

First Prize, Fred Osterman, International Harvester Co., Rock Island, Ill.
Second Prize, John Waddington, Brown & Sharpe Mfg. Co., Providence, R. I.
Third Prize, Albert Lamp, Blackhawk Foundry & Machine Co., Davenport, Ia.

Judges:

Harry Peschel, Allis-Chalmers Mfg. Co., Milwaukee.
John H. Champion, Nordberg Mfg. Co., Milwaukee.
Oscar Woehlke, Liberty Foundry, Inc., Wauwatosa, Wis.

Pattern Making

Recommended for prizes in Pattern Making Contest:

First Prize, Fred Henz, Western Pattern Works, Cleveland, Ohio.
Second Prize, Alex Allardyce, Murray Corp. of America, Detroit, Mich.
Third Prize, George Sharrar, French & Hecht, Inc., Davenport, Ia.

Judges:

G. G. Mikkelson, Boys Technical High School, Milwaukee.
W. H. Schmitt, Falk Corp., Milwaukee.
J. F. Schnaufer, Acme Pattern Works, Milwaukee.

Mr. Kennedy then explained how the contests were conducted, adding that the appropriations for prizes were made from funds under control of the Board of Awards.

President Wick next called for the report of the Resolutions Committee, which had been appointed to prepare a resolution on the death of Past-President Fred Erb. The resolution follows:

Resolution on Death of Past-President Fred Erb

BE IT RESOLVED, that in the death of Fred Erb the American Foundrymen's Association, as well as the Gray Iron Foundry Industry, has lost one of its most beloved members.

Fred Erb was not only a highly successful foundryman and business executive, but he also had the priceless faculty of making and keeping friends. He had friends because he was a friend, and he enjoyed the confidence and esteem of all who knew him. His life is a bright and glorious example of sterling personal integrity. His thoughtful consideration and substantial help to his fellow foundrymen, less fortunate than himself, was known only to a few of his closest associates.

BE IT RESOLVED, that Fred Erb will be greatly missed by all of us, and that we, the members of the American Foundrymen's Association, extend our deepest sympathy to his wife and children.

Following the reading of this resolution, Frank J. Lanahan moved its adoption. On being seconded by L. N. Shannon, the members, in voting approval, stood in silent memorial.

John H. Ploehn, a member of the Apprentice Training Committee, presented a recommendation from this committee:

"That all indentured apprentices be sold the Bimonthly Transactions for two dollars a year, as a help to the boys as future members, this price to be made available to boys indentured to members of the Association".

Mr. Ploehn then offered this recommendation as a motion, with the provision that it be presented to the Board of Directors for consideration. On being seconded by E. H. Ballard, it was put to vote and carried.

There being no further business to come before the meeting, President Wick declared it adjourned.

SHOP OPERATION COURSE (Session 5)

Thursday, May 6, 4:00 P. M.

Chairman—L. G. Korte, Atlas Foundry Co., Detroit, Mich.

This session was given over to the discussion of *Gating and Riserling* with the discussion being led by Rex Jennings, John Deere Tractor Co., Waterloo, Iowa.

ANNUAL DINNER

Thursday, May 6, 7:00 P. M.

The annual dinner was unusually successful from every standpoint. With over 600 in attendance, the affair was held in the Ballroom of the Hotel Schroeder, with President James L. Wick, Jr. presiding. The Milwaukee Lyric Male Chorus entertained during dinner intervals with a most impressive and enjoyable concert. Following the dinner, President Wick announced that the Association was making awards of three of its gold medals for outstanding achievement in the foundry industry and introduced Past-President E. H. Ballard.

Mr. Ballard, on behalf of the Association, presented to John Ward Bolton, metallurgist, Lunkenheimer Co., Cincinnati, the John A. Penton Medal "in recognition of work in metallurgy and the practical application of research to the advancement of the foundry industry".

Past-President R. A. Bull was next called on to present to Charles Willers Briggs, physical metallurgist, Naval Research Laboratory, Washington, D. C., the William H. McFadden Medal "for direction of important research work and published writings on metallurgy of great value to steel castings producers."

The third award was made on behalf of the Association by Past-President Dan M. Avey. This award was the J. H. Whiting Gold Medal, presented to Dr. James Tucker MacKenzie, metallurgist, American Cast Iron Pipe Co., Birmingham, Ala., "for important and practical work in the advancement of gray iron foundry practice."

In accepting the medal awards, each recipient responded with very appropriate acknowledgments.

The principal address of the evening was delivered by Dr. James Shelby Thomas, president, Chrysler Institute of Engineering, Detroit, and Clarkson College of Engineering, Potsdam, N. Y. Dr. Thomas' address covered in a most interesting manner the subject of "What the Machine Has Done to Mankind."

GRAY CAST IRON

Friday, May 7, 10:00 A. M.

Chairman—J. W. Bolton, Lunkenheimer Co., Cincinnati, Ohio.

Vice-Chairman—H. H. Judson, Goulds Pumps, Inc., Seneca Falls, N. Y.

The following papers were presented and discussed:

Some Steel Works Castings, by J. Roxburgh, Davy Bros., Ltd., Sheffield, England. This was the Annual Exchange paper and was presented on behalf of the Institute of British Foundrymen. In absence of the author, J. W. Kleler, assistant superintendent foundries, Allis-Chalmers Mfg. Co., Milwaukee, Wis., presented the paper.

Graphitization and Inclusions, by J. W. Bolton, Lunkenheimer Co., Cincinnati, O.

Titanium in Cast Iron, by E. R. Starkweather, Titanium Alloy Mfg. Co., Niagara Falls, N. Y.

NON-FERROUS FOUNDRY PRACTICE

Friday, May 7, 10:00 A. M.

Chairman—H. J. Roast, Canadian Bronze Co., Ltd., Montreal, Canada.

Vice-Chairman—T. C. Watts, Falcon Bronze Co., Youngstown, Ohio.

The following papers and committee reports were presented and discussed:

Production of Pressure Tight Castings in 30% Cupro-Nickel, by T. E. Kihlgren, International Nickel Co., Bayonne, N. J.

X-Ray as an Aid in the Production of Aluminum Castings, by Geo. Stoll and A. T. Ruppe, Bendix Corp., South Bend, Ind. This paper was presented in abstract form by Mr. Stoll.

Problems in Bronze, by Harold J. Roast, Canadian Bronze Co. Ltd., Montreal, Canada.

Report of Committee on Analysis of Defects, by H. M. St. John, Detroit Lubricator Co., Detroit, Mich.

Report of Committee on Recommended Practices, by H. J. Rowe, Aluminum Co. of America, Cleveland, O.

Tribute to the Memory
of
Robert Alexander Bull

Whereas, the active, useful life of Robert A. Bull, a man respected for his knowledge and loved for his friendly character by those connected with his chosen field, the foundry industry, has suddenly been halted, and,

Whereas, throughout his extended active participation as a member of the American Foundrymen's Association, as Vice President in 1911, in 1913 and again in 1914 and as President for two terms, in 1915 and 1916, he gave generously of his time and talents, and,

Whereas, suddenly breaking all ties, he enlisted in the United States Army and went to France to serve during the regrettable period of the war, returning with the rank of Major, and,

Whereas, on returning home he continued to work and share the results of his work in a measure recognized by the award in 1927 of the Seaman Gold Medal, and

Whereas, it may be truthfully said of him,
*"What, to him, was sleepless toil?
Or what the ease that fortune lend;
Work consumed his midnight oil
Whose joy did outward good transcend."*

Now Be It Resolved:

That we, his associates of the American Foundrymen's Association declare our everlasting respect and affection, our admiration of his talent and accomplishment and thus express our thanks for all he gave of his store of knowledge and our deep sorrow at parting.

Further Be It Resolved: That this tribute be spread upon the official records of the Association and that a suitable copy be presented his wife and family.

Committee on Resolution

H. BORNSTEIN, *President*

GUILLIAM H. CLAMER

C. E. HOYT, *Executive Vice President*

LAMAR PEREGOY

BENJAMIN D. FULLER

July 29, 1937

The day we commemorate

Reports of Board of Directors and Executive Committee Meetings

FOLLOWING the annual meetings of the Board of Directors on July 23, 1936 in Cleveland, which were reported on Bound Volume 44, official meetings were held as follows:

September 30, 1936, Chicago—Meeting of Executive Committee.

October 19, 1936, Youngstown, O.—Joint Meeting of Executive and Policy Committee.

December 4, 1936, Chicago—Executive Committee and Board of Directors.

May 3, 1937, Milwaukee, Wis.—Special Meeting of Board of Directors.

July 20, 1937, Chicago—Final Meeting of the 1936-37 Board of Directors, and First Meeting of the 1937-38 Board of Directors.

September 22, 1937, Chicago—Meeting of Executive Committee.

Minutes of these meetings are given below.

Minutes of Meeting Executive Committee

CHICAGO, SEPTEMBER 30, 1936.

Members present: James L. Wick, Jr., President, H. Bornstein, Vice-President; Directors, D. M. Avey, E. O. Beardsley, L. S. Peregoy and Executive-Secretary C. E. Hoyt.

Others present: R. E. Kennedy, Technical Secretary and E. O. Jones, Director of Safety and Hygiene Section.

President Wick, presiding, announced the first order of business would be the time, place and character of the 1937 convention, calling attention to a supplementary communication from Milwaukee setting forth facilities their Auditorium offered for a meeting, and urging favorable consideration of Milwaukee for a joint Convention and Exhibit in 1937.

This communication, setting forth the many advantages Milwaukee offered, pledged the Milwaukee Chapter to secure membership of every foundry in the state of Wisconsin having 50 or more employees, which pledge the 11 officers and directors of the Chapter signing the letter agreed to underwrite, if necessary.

With the question of an Exhibit in '37 thus presented to the Execu-

tive Committee, consideration was given to exhibit facilities available in other cities who had extended invitation for 1937.

Following discussion, Mr. Bornstein moved that it be the recommendation of the Executive Committee to the Board of Directors, that a Convention with an Exhibit be held in Milwaukee beginning the week of May 3, 1937. Motion seconded by Mr. Perego and unanimously carried.

Discussion then followed as to limitations, if any, that should be placed on exhibits. It was agreed that the Manager of Exhibits confer with representatives of companies who, when no limitations were placed, had in years past staged large exhibits—ascertain their views and wishes—come to some agreement, and be governed accordingly.

It was understood, that regardless of what limitations might be agreed upon, this exhibit should not be advertised as a limited one which might tend to decrease interest.

On motion duly seconded, the Secretary was instructed to submit all these recommendations forthwith to the Directors for letter ballot, and if approved by them, announcement should be made for release October 15.

Report of Ballot on Amendments to By-Laws

President Wick called for a report of judges appointed to canvass the ballot of members on amendments to By-Laws, reading as follows:

We, the undersigned members of committee appointed by you to canvass the ballots cast on the Amendments to the By-Laws of the American Foundrymen's Association, are pleased to report that we have done so. The committee met on Wednesday, September 23, to report the following results of its canvass:

Total number of ballots cast—651; Affirmative 647—Negative 5.

Signed: W. C. Packard, *Chairman*; H. W. Johnson and N. F. Hindle.

Apprentice Memberships

Secretary Hoyt read a communication from M. J. Gregory, factory manager, foundry division, Caterpillar Tractor Co., Peoria, Ill., advocating some provision for foundry apprentice memberships in A.F.A.; also, letters from T. J. Frank, Chairman of the Quad City Chapter and P. T. Bancroft in support of Mr. Gregory's recommendations.

Secretary Hoyt reported that he had submitted to these gentlemen for their consideration, a three-way split of the \$6.00 Affiliate membership, namely—the Association to write off \$2.00, the employer pay \$2.00 and the apprentice pay \$2.00.

Following discussion, it was moved by Mr. Perego, seconded by Mr. Avey, that the President be authorized to submit such a plan to the Board of approval by letter ballot, provided it was first approved by Messrs. Gregory, Frank and Bancroft, with the understanding that such apprentice memberships be limited to those under 25 years of age; and the further limitation, that such members should not be entitled to vote or hold office, but would enjoy such privileges and would receive such publications as were from time to time agreed upon by the Board of Directors.

All were agreed that it would not be wise to amend or add to the

membership provisions of the By-Laws. The question of extending such privileges to students in engineering and trade schools was considered, but no action was taken.

Change in Plan of Refund of Dues to Chapters

Secretary Hoyt requested authorization from the Executive Committee to make refund to Chapters, as of date of October 15, the full 15 per cent of dues paid by members of Chapters, instead of 50 per cent of this amount as provided for in the manual for conduct of Chapters. On motion duly seconded, such procedure was authorized.

Insurance Coverage for Illinois Foundrymen

E. O. Jones, Director of the Safety and Hygiene Section, reported bulletins issued and service rendered to foundrymen in Illinois, in connection with the recently enacted laws covering occupational disease compensation, effective October 1. He then outlined plan that had been developed for securing group insurance for those foundries who could not secure coverage from their regular carriers. This plan, while fostered by A.F.A., would not place any financial obligations on the Association.

After hearing these reports, the Committee voted unanimously to approve and authorize further negotiations to the end, that the desired and needed coverage be provided.

Foundry Sand Research

Mr. Kennedy reported progress on foundry sand research proposal and the raising of special funds authorized at the Board meeting July 23. Discussion followed as to the practicability of attempting to raise a general research fund rather than one for special purposes.

Mr. Bornstein presented the possibility of securing funds by sustaining or contributing memberships, stating that the larger companies were able and should be willing to augment their membership contributions by this means.

Mr. Kennedy then presented a program for molding sand research submitted by Dr. Ries. On motion duly seconded, it was approved.

Mr. Kennedy mentioned the desirability of having on the Advisory Committee for this project, two or three steel foundrymen. This also was approved.

Design of Steel Castings

Mr. Kennedy also reported progress on the development of a treatise on the design of Steel Castings, appropriation for which was authorized at the Board Meeting July 23. A communication from Major R. A. Bull, setting forth an acceptable financial arrangement for doing this work, was read, whereupon it was moved by Mr. Avey, seconded by Mr. Peregoy, that the arrangements be approved and Major Bull so advised. Copies of this action to be mailed to Mr. Locke and Mr. McKinney of the Special Committee.

Mr. Hoyt read correspondence with Past Director George Batty, relative to awards being given to certain individuals who had presented

valuable papers and reports of researches for publication in A.F.A. Transactions. It was stated that this question had been referred to the Board of Awards for their consideration and no further action was taken at this time.

Chapter Extension

Secretary Hoyt reported a chapter membership study that had been prepared by Mr. Hindle—an extensive survey of all industrial centers showing membership income that would be available to a chapter on the basis of present membership; also, the record of non-member foundries in each proposed chapter territory. It was his suggestion, that under the direction of Mr. Bornstein as general membership chairman, an effort be made to build up the A.F.A. membership in these potential chapter territories to a point where the organization of a chapter would be demanded by members in said territory.

Charts of Association activities and organization were presented to each member for study and suggestions before final charts were published. President Wick called attention to the need for an index and was told this would be added.

Secretary Hoyt reported, that beginning August 1 the Penton Press Company was making a charge of \$25.00 per month for storing type for the Cast Metals Handbook. Following discussion, it was moved by Mr. Peregoy, seconded by Mr. Beardsley and carried, that the type be scrapped saving storage costs.

On motion, the meeting stood adjourned.

Respectfully submitted,

C. E. HOYT, *Secretary*.

Minutes of Joint Meeting Executive and Policy Committees

YOUNGSTOWN, OHIO, OCTOBER 19, 1936.

Members Executive Committee Present: President James L. Wick, Jr., Vice President H. Bornstein, Directors D. M. Avey, L. S. Peregoy, W. L. Seelbach, Executive Secretary C. E. Hoyt.

Members Policy Committee Present: James L. Wick, Jr., L. S. Peregoy, W. L. Seelbach, H. S. Simpson.

Meeting was called to order by President Wick, who, reporting on the absence of Mr. Lanahan, who had on October 6 lost, through death, his wife and life companion, requested all present to join with him in silent tribute to the one member of our official group who always had in times past been so helpful in extending sympathy to those experiencing sorrow and grief. Mr. Wick, continuing, stated that A.F.A. was officially represented at the Solemn High Mass of Requiem for Mrs. Lanahan at St. Paul's Cathedral, Friday, October 9, by himself, Past President D. M. Avey and Secretary C. E. Hoyt.

Mr. Wick announced that in the absence of Mr. Lanahan, Chairman

of the Policy Committee, they would proceed with a joint meeting of the Policy and Executive Committees, calling on Secretary Hoyt to read the minutes of meeting of Executive Committee held at the office of the Association in Chicago, September 30. On motion, minutes were approved as read.

Mr. Wick then called on Secretary Hoyt to read a summary of Policy Committee activities which had been prepared. The report follows:

"Evolving from a general round-table conference attended by some 35 officers, directors and past officers, on the occasion of the Alumni Dinner May 4, 1936, a Policy Committee of five, consisting of Frank J. Lanahan, Chairman, and representing Malleable; James L. Wick, Jr.—Non-Ferrous; L. S. Peregoy—Steel; W. L. Seelbach—Gray Iron; and H. S. Simpson—Equipment, was appointed to consider and suggest plans and policies for the future development of the Association.

"This committee sought and obtained, by correspondence, suggestions for their consideration, many of them advocated by more than one of the members responding.

"From these, a summary of suggestions was then prepared and discussed at the meeting of the Committee held in Cleveland, July 22, preceding the annual Board meeting held the following day. At this meeting there were present, in addition to the members of the Committee, the following directors of A.F.A.: H. Bornstein, H. S. Washburn, E. H. Ballard, Rufus Harrington, E. O. Beardsley.

"From the suggestions offered, it was agreed to incorporate into the records of this meeting the following for further consideration:

1. Extend the A.F.A. membership to the end that it includes representation of more nearly 100 per cent of all progressive foundries in each branch of the casting industry; to establish local Chapters as conditions justify, and through well planned concerted effort, help to raise and maintain the standard of work of present Chapters.
2. Continue to advocate and provide direction for technical training of apprentices, employees and supervisory forces.
3. Stimulate and provide direction for broadening the knowledge of those engaged in the design of castings on the utility of cast products.
4. Continue to encourage, direct, and amplify technical research on the products of the entire castings industry.
5. Sponsor cooperative effort on the part of all interests in promoting increased uses of castings through directing attention to merit and application of cast products.
6. Continue to stimulate investigations and education in the matter of costs.
7. Assist in developing for each of the casting groups, some system of selling by price classification.
8. Stimulate and direct improvement of pattern equipment.
9. Cooperate in effecting acceptable standards for materials and equipment used in foundries.
10. Point out obsolescence and show advantages of modernization.
11. Coordinate and disseminate through A.F.A. State Policy Committees, information helpful in securing equitable occupational disease legislation.
12. Foster and promulgate industry codes covering suppression and control of foundry dust, gases and fumes.
13. Coordinate and disseminate information of assistance in combating in every legitimate way unfair compensation and occupational

disease insurance rates, and when advisable provide for some form of group insurance for members of the foundry industry.

14. Sponsor some broad comprehensive program for bringing the whole industry together to act as a unit in matters of public policy.

15. Sponsor the development of workable code of ethics for the foundry industry.

16. Assume leadership in making industry more articulate to the end, that the increasing utility of all classes of castings may result advantageously to all persons engaged in the foundry and related industries, and to all users of foundry products."

Secretary Hoyt in commenting on the above summary, prepared from suggestions submitted for the Committee's consideration, said:

"Any compilation of activities of the nature of those outlined cannot be definitely established. They should be subject to change to meet the changing things of the world, and any declaration published should be sufficiently elastic to permit meeting conditions as they arise.

"As the one National organization representing all branches and classes of castings manufactured, the A.F.A. has a responsibility as the spokesman for the foundry industry of America.

"To function satisfactorily, it is obvious that the Association cannot be the voice of any group or class, and obviously it cannot assist in merchandising the products of one group of the industry in competition with other groups; but it can and should act as the advocate for and seek all means to promote cast products in competition with all other products.

"While the responsibility of the Association to employers and employees alike is recognized, it cannot function as a partisan in the questions of management and labor problems. It can, however, be effective in educating all foundry employees on the technical and operating procedures of casting production, and more broadly on the fundamental economics of business.

"Further, it can and perhaps should be recognized as an effective aid in securing for member plants the services of capable plant executives, and in providing jobs to those that merit them.

"Obviously, in promoting public relations or in any of its activities, A.F.A. cannot be aligned with any political party. However, there might develop occasion where it could and should, as the representative of one of the great basic industries of the country, cooperate with other organizations in combating political thinking detrimental to the industry.

"General research work should be undertaken that is of advantage to all groups of casting manufacturers, such for instance as our well established foundry sand research work. Further than that, the Association should help to promote, organize and raise funds for research directly beneficial to any particular branch of the industry.

"No individual type or make of equipment, processes or materials should be promoted by the Association, but the active study of approved products obtainable through modern equipment should have the support of the organization.

"In this particular, its functions as set forth in its Articles of Incorporation; of providing periodic displays of foundry materials and machinery, has furthered and should continue to further the advance of both the foundry and foundry equipment industries.

"It should be obvious to you of the Committee and to the Board to whom you will submit your report and recommendations, that all that is outlined cannot be accomplished by paid officers and staff

alone. Furthermore, it cannot be financed on the income available through payment of present low membership dues. Therefore, thought should be given to some plan for securing increased revenue that would do away with the necessity of raising special funds for special purposes, as has been necessary in the past.

"It obviously is the duty of a national association of any industry to give thought to the protection of the interest of its members, to broaden the opportunities available to all within the industry, to endeavor to foresee and forestall destructive tendencies, to unify effort, and to make industry articulate to its members, customers, and the public.

"This broad general program you have under consideration cannot be undertaken and most certainly cannot prove successful for the foundry industry without the leadership of those men who are the executives of the progressive foundries of the country, giving their united support to a staff of executives who should have the vision and the ability to help organize industry and direct its activities.

"Our By-Laws have recently been amended to provide for additional executives, and we should look forward to a re-alignment of our executive staff at an early date. In considering any additions to the staff, consideration should perhaps be given, first, to the qualifications and capacities of those now on the staff for carrying on not only accepted and recognized activities, but proposed new activities. Then, the selection of any additional staff members should be governed by their qualifications for making this staff more effective.

"In conclusion, may we suggest that your Committee's efforts might properly be devoted to considering means of stimulating our present accepted functions, and then the desirability of undertaking new ones proceeding as follows:

1. Approval, rejection or extension of suggested activities.
2. Develop plans for financing any broader field of work approved.
3. Prepare statement of general policies.
4. Consider addition to office staff personnel in accordance with amended By-Laws.
5. Submit complete plan to Executive Committee for their consideration, and then joint recommendations to the Board of Directors for their consideration, approval or rejection."

In the discussion following the above presentation by the Secretary, it appeared to be the consensus of opinion that the first step should be the reorganization of the A.F.A. staff in accordance with the provisions of the By-Laws as recently amended. To that end it was moved, that the President, Vice-President and Executive Secretary be authorized to study the situation, canvass the field for additional personnel, and submit recommendations to the Board of Directors. Motion seconded and unanimously carried.

Secretary Hoyt presented a statement covering the activities of the Safety and Hygiene Section as developed since the Executive Committee meeting held in Chicago, September 30. At that meeting the Secretary reported on the situation in Illinois resulting from enactment of occupational disease legislation, which became effective October 1, 1936.

Discovering that many members and other foundries in the state were experiencing difficulty in securing occupational disease coverage, from either stock or mutual companies, they assumed responsibility under leadership of E. O. Jones, Director of Safety and Hygiene Section of A.F.A., for providing group insurance.

This resulted in the A.F.A. sponsoring, with the approval of the Executive Committee, an organization under the name American Founders Compensation Group. O. E. Mount, American Steel Foundries; R. D. Phelps, Francis and Nygren Foundry Company; Roger Bronson, F. S. James and Company (Underwriters); and E. O. Jones, all of Chicago, being invited to act as temporary trustees. These gentlemen accepting this responsibility, met and organized by electing Mr. Mount chairman of the temporary board of trustees, and E. O. Jones, Secretary-Treasurer. They have opened an account at the Harris Trust & Savings Bank in the name of American Founders Compensation Group, and, through F. S. James and Company, have arranged for reinsurance under Lloyds London. As now set up, the Association will have no financial obligation, but having accepted the responsibility on behalf of foundries in distress they have a moral obligation to see the program through.

Secretary Hoyt, continuing, stated that through an agreement with the trustees and with F. S. James and Company, A.F.A. would be reimbursed for expenses, rent and administration services.

The members of the Executive Committee present who had been kept advised of this development, approved the procedure that had been followed and expressed the opinion that steps taken would prove definitely beneficial not only to the foundries in Illinois but in other states as well.

Vice-President Bornstein, General Chairman of the Membership Committee, reported a conference held in Chicago with members of the staff, Thursday, October 15, and outlined plans that were being developed for a general membership campaign working through membership committees of Chapters.

Secretary Hoyt reported that the recommendations of the Executive Committee that a convention and exhibit be held in Milwaukee, May 3 to 7, 1937, had been approved by unanimous letter ballot of Directors (one Director asked to be excused from voting). He reported further, that with this approval a release announcement had been prepared for publication as of date of October 15, and that a copy of this release had been mailed under date of October 12 to all former A.F.A. exhibitors.

With expressions of appreciation for the splendid hospitality President Wick had dispensed on this occasion, the meeting, on motion duly seconded, stood adjourned.

Respectfully submitted,

C. E. HOYT, *Secretary.*

Minutes of Meeting of the Executive Committee and Board of Directors

CHICAGO, DECEMBER 4, 1936.

Members of Executive Committee present: President J. L. Wick, Jr., Vice President H. Bornstein, Directors L. S. Peregoy, E. O. Beardsley, D. M. Avey, Executive-Secretary C. E. Hoyt.

Others present: Director J. R. Allan, Technical Secretary R. E. Kennedy, Director of Safety and Hygiene Section E. O. Jones.

President Wick presiding stated that while this was a meeting of the Executive Committee, it could also be considered as a meeting of the Board as notice had been sent to all Board members inviting them to attend and if they did not attend to send proxies to be voted in the election of an Executive Vice-President and a Secretary-Treasurer.

Proxies were received from the following Directors to be voted by President Wick: E. W. Campion, W. L. Seelbach, Frank J. Lanahan, Sam Tour, W. J. Cluff, H. S. Washburn, Carl C. Gibbs, Marshall Post, and L. N. Shannon.

Secretary Hoyt read the minutes of the meeting of the Executive Committee and Policy Committee held October 19. On motion, minutes were approved as read.

Minutes of the meetings of September 30 and October 19 had been mailed to all members of the Board and of the Advisory Board.

A report of the Special Committee of Three appointed at the meeting, October 19, to canvass the field for additional personnel to complete the official staff in accordance with the amended by-laws was read by Secretary Hoyt. It was stated that copies had been mailed to all Board members under date of November 28.

President Wick announced that in accordance with the recommendations of the Committee, first in order would be the resignation of C. E. Hoyt as Executive Secretary-Treasurer, whereupon Mr. Hoyt tendered his resignation as Executive Secretary-Treasurer effective December 31, 1936. On motion by Mr. Bornstein, seconded by Mr. Beardsley, Mr. Hoyt's resignation was accepted.

President Wick then announced that next in order would be the election of an Executive Vice-President and called for nominations. Mr. Bornstein nominated C. E. Hoyt for that office and there being no further nominations, they were declared closed. On motion by Mr. Bornstein, seconded by Mr. Peregoy, C. E. Hoyt was unanimously elected, he to assume that office January 1, 1937.

President Wick announced that next in order would be the election of a Secretary-Treasurer and that nominations were in order.

Mr. Bornstein nominated Dan M. Avey, and upon his nomination being seconded, the Chair called for a vote which was unanimously given, whereupon President Wick declared Dan M. Avey unanimously

elected to the office of Secretary-Treasurer of the American Foundrymen's Association, he to assume that office January 1, 1937.

President Wick announced that the Finance Committee of the Board was composed of the immediate past President, the President, and the Vice-President, with the immediate past President acting as Chairman of the Committee and that Mr. Avey as immediate past President was Chairman of the Finance Committee at this time.

Mr. Avey stated that due to his election as Secretary-Treasurer, he felt it would be in order to resign as Chairman of the Finance Committee and would so do. On motion duly seconded, Mr. Avey's resignation was accepted.

President Wick stated that retroactively Frank J. Lanahan, who had served for two years as Chairman of the Finance Committee during President Avey's administration, would again become Chairman of the Committee. On motion duly seconded, Mr. Lanahan was made Chairman of the Finance Committee.

President Wick stated that the changes in officers as of January 1 would require new resolutions covering funds deposited in the bank and signatures for the withdrawal of funds.

On motion duly seconded, the following resolutions were unanimously passed:

Resolved that resolutions authorizing withdrawal of funds required by the Harris Trust and Savings Bank of Chicago or any other approved bank where funds are deposited are hereby approved and the Secretary authorized to certify thereto.

Resolved that checks for withdrawal of funds in the general checking account, all interest savings accounts, and all securities in sinking funds of the American Foundrymen's Association shall require the signatures of any two of the following officers of the Association: James L. Wick, Jr., President, H. Bornstein, Vice-President, C. E. Hoyt, Executive Vice-President, D. M. Avey, Secretary-Treasurer.

Resolution on bonds for Secretary-Treasurer—it was moved by E. O. Beardsley that the bonds of C. E. Hoyt as Secretary-Treasurer be released and a new bond made out in the name of D. M. Avey, Secretary-Treasurer as of January 1, 1937. Motion seconded by Mr. Perego and carried.

President Wick announced that the next order of business would be the fixing of salary compensation for the newly elected officers of the Association. Following discussion it was moved by Mr. Bornstein, seconded by Mr. Perego, that the salary of C. E. Hoyt as Executive Vice-President be a continuation of the salary voted to him as Executive Secretary-Treasurer at the annual Board meeting.

It was moved by Mr. Perego, seconded by Mr. Beardsley, that the salary compensation of Dan M. Avey as Secretary-Treasurer from January 1 to June 30, the end of the fiscal year, be as determined and arranged for by the Finance Committee. Motion carried.

Publication Policy

President Wick read Secretary Hoyt's report on publication policies presented at the annual Board meeting, July 23. The recommended changes in publication policies were discussed, following which Mr. Bornstein moved that the President be authorized to appoint a Publication

Committee to consider publication policies and be in charge of the direction of publications of the Association, subject to the approval of the Board and that D. M. Avey be appointed as Secretary of this Committee. Motion seconded by Mr. Peregoy and carried.

Alloy Cast Iron Committee Report

Technical Secretary Kennedy presented a report on the status of the Alloy Cast Iron publication and reported that the Alloy Cast Iron Committee favored having this publication issued as a special publication of the Association, copies being sold to members of the Association at a price considerably less than that to non-members.

The Committee further recommended that the expense of publication be borne in part by the insertion of advertisements, these to be solicited from alloy casting producers, manufacturers of alloy materials, and any manufacturers of equipment relating to alloy casting production.

No action was taken on the report and the President announced that he would refer it to the Publication Committee.

Industrial Hygiene Codes Committee Report

James R. Allan, Chairman of this Committee, presented two codes developed by his Committee on Hygiene. Following discussion, it was voted to approve for publication as tentative codes of recommended practices for the foundry industry, the following:

Tentative Codes of Recommended Practices for Grinding, Polishing and Buffing Equipment Sanitation, and

Tentative Code of Recommended Practices for Testing and Measuring Air Flow in Exhaust Systems.

On motion duly seconded it was voted to make these codes available at the price of \$2.00 per copy with special discounts to members of A.F.A.

On motion duly seconded, Mr. Allan and his Committee were tendered a vote of thanks for the splendid work they had done in the preparation of these codes and the work they are doing in the preparation of further codes.

American Founders Compensation Group

E. O. Jones, Director of the Safety and Hygiene Section, submitted a comprehensive report on the work of the American Founders Compensation Group fostered by A.F.A. and administered by the following trustees: O. E. Mount, American Steel Foundries, R. D. Phelps, Francis & Nygren Foundry Co., Roger Bronson, F. S. James Co., and E. O. Jones, A.F.A.

Following a statement of the financial operations of this group and a statement of the customary procedure and administration charges made by both stock and mutual companies, it was moved by Mr. Peregoy, seconded by Mr. Beardsley, that A.F.A. ask the trustees of the Compensation Group to authorize their treasurer to reimburse the A.F.A. to the amount of 8 per cent of insurance premiums to be applied toward defraying the cost of administrative services, rent, stenographic, clerical and other expense.

Manager of Exhibits' Report

Mr. Hoyt presented a progress report on the exhibit to be staged at Milwaukee. In conclusion he asked Executive Committee action on rules and regulations to govern the conduct of the exhibit and on price to be charged for space.

It was moved by Mr. Avey, seconded by Mr. Bornstein, that the usual rules and regulations for the conduct of A. F. A. exhibits be approved as adapted to conditions that would prevail at Milwaukee. Motion carried.

It was moved by Mr. Beardsley, seconded by Mr. Perego, that the price for space should range from \$1.00 to \$1.25 per square foot, with a premium of 5 to 20 per cent on preferred corner locations and that in general the minimum rate should apply to spaces of greatest depth and maximum rate to spaces of shallowest depth. Motion carried.

Contract With Milwaukee Auditorium

Mr. Hoyt explained that he had written agreements with the Milwaukee Auditorium and with the Milwaukee Association of Commerce for the use of exhibition space in the Auditorium either on a straight rental rate—the Association to supply booths, signs, janitor service, etc.—or the option of an all-inclusive rate on a per-square-foot basis.

On motion duly seconded, the Manager of Exhibits was authorized to enter into contractual agreement with the Milwaukee Auditorium on whatever basis the officers believed would be most satisfactory.

Appropriation for Apprentice Contest

Mr. Kennedy reported that arrangements were being made for conducting a molding and pattern making apprentice contest at the Milwaukee convention and requested that appropriations be made for funds for prizes, in steel molding, iron molding, non ferrous molding, and patternmaking, with first, second, and third prizes for each group.

It was moved by Mr. Perego that the Board of Awards be requested to make the usual appropriation for prize fund. Motion seconded by Mr. Beardsley and carried.

Obermayer Award Fund

Messrs. Hoyt and Kennedy presented the history of the Obermayer award prize and asked for suggestions as to how this might best be used at the next convention.

A number of suggestions were made with all present being in agreement that prizes be awarded for the best "idea or device for Safety or Health protection, or ideas that would stimulate greater interest in safety on the part of workers in the foundry or pattern shop."

It was further agreed that contestants for cash prizes of \$50.00 and \$25.00 be limited to foremen, apprentices, or shop workmen in a foundry or in some department of a plant operated in connection with a foundry or pattern shop.

On motion duly seconded, it was voted to ask the approval of the donors and of the Board of Awards for staging such a contest at the Milwaukee convention.

Financing Local Chapters

A communication was read from W. B. Coleman, Chairman of the Philadelphia Chapter, requesting consideration of ways and means of increasing financial assistance to chapters. Following discussion, it was suggested that the President and Executive Secretary correspond with Mr. Coleman in an effort to help solve a problem which the Philadelphia Chapter alone appeared to be confronted with.

Membership classes and dues were discussed, whereupon it was moved that Mr. Bornstein, as Chairman of the Membership Committee, be appointed a Committee of One to work with the officers in considering revisions in classes of membership and dues. Motion carried.

Making Attendance At Conventions More Profitable

Plans were discussed for making attendance at conventions and exhibits of greater value to those foundries whose representatives were in attendance. It was suggested that a communication be addressed to a group of well-known foundrymen soliciting their opinions as to the value of attendance and what they expected or desired their representatives to submit reports on. Mr. Allan suggested that they also be asked to submit short statements as to the value of A.F.A. membership which could be used in promoting increased membership.

Abatement of Excessive Entertainment and "Bootleg" Exhibits

Mr. Hoyt called attention to the signed agreements he had with all Milwaukee hotels prohibiting use of rooms for exhibit purposes and promising cooperation in the abating of excessive room entertainment.

Discussion then followed on the resolutions passed unanimously by the Boards of Directors of the A.F.A. and the F.E.M.A. in 1930 for the purpose of discouraging excessive room entertainment, action which was almost unanimously approved by exhibitors of that year.

Mr. Hoyt stated that these resolutions were reaffirmed by the Boards of Directors of the A.F.A. and the F.E.M.A. in 1936 and published to exhibitors and members.

Following discussion, Mr. Perego proposed the following resolutions which were seconded by Mr. Bornstein and unanimously carried:

Resolved that the Board of Directors of the American Foundrymen's Association record its appreciation of the cooperation of exhibitors and members in the abatement of excessive entertainment at conventions, and

Be it further resolved that they now reaffirm the resolutions unanimously approved by the Boards of Directors of the American Foundrymen's Association and the Foundry Equipment Manufacturers Association in 1930 setting forth that the practice of promiscuous and wholesale entertainment of customers and others with special reference to wholesale dispensation of liquor at conventions and exhibits should be discountenanced, believing that such practices detract from and tend to defeat the purposes of Foundrymen's Week.

Be it further resolved that the Board of Directors of the American Foundrymen's Association, acting on behalf of its Members and Exhibitors, reaffirm its disapproval and determination to discourage any organization or individual from using hotels and any other place

for any purpose during Convention and Exhibition hours that would tend to detract from attendance at meetings and exhibits.

Be it further resolved that cooperation be requested of all companies and their representatives in attendance at the Milwaukee convention in the carrying out of the intent of the above resolutions to the end that Foundrymen's Week may serve the purpose of promoting the best interests of the Foundry Industry.

On motion, the meeting stood adjourned at 5:30 P. M.

Respectfully submitted,

C. E. HOYT, *Secretary.*

Minutes of Special Meeting of Board of Directors

HOTEL SCHROEDER, MILWAUKEE, MAY 3, 1937.

The meeting was called to order by President James L. Wick, Jr.

Members present: Vice-President Hyman Bornstein, Directors E. O. Beardsley, E. W. Campion, Frank J. Lanahan, Sam Tour, W. J. Cluff, L. S. Peregoy, F. A. Sherman, J. S. Washburn, L. N. Shannon, James R. Allan; Marshall Post; Executive Vice-President C. E. Hoyt; Secretary-Treasurer, Dan M. Avey; Technical Secretary, R. E. Kennedy.

Resolutions on the deaths of Past-President Fred Erb and Past-Director George Batty, were presented and unanimously adopted.

By resolution, the following were recommended for election as honorary life members of the Association: James L. Wick, Jr., J. W. Bolton, J. T. MacKenzie and Charles W. Briggs.

A petition from the members of the Association in the Buffalo area requesting the establishment of a chapter was presented. This petition was accepted and the executive officers were authorized to establish the chapter and define the territory to be embraced by the new chapter.

On motion the meeting recessed to meet immediately following the annual meeting.

CONTINUATION SPECIAL MEETING OF BOARD OF DIRECTORS

HOTEL SCHROEDER, MILWAUKEE, MAY 6, 1937.

The special meeting of the Board of Directors, recessed from that held on May 3, was called to order at 5:30 P. M., May 6, in the Hotel Schroeder by President Wick.

On motion of Mr. Allan, seconded by Mr. Shannon, the Board confirmed the appointment of a Fact-Finding Committee to advise the Board on policies and on ways and means. The President announced that he had appointed F. J. Lanahan, Chairman; Hyman Bornstein, E. H. Ballard, L. S. Peregoy, Sam Tour, Marshall Post and H. S. Simpson; with President Wick, C. E. Hoyt and Dan M. Avey ex-official members of this Committee, and requested the committee to report its findings at the annual Board meeting in July.

Meeting adjourned.

Respectfully submitted,

DAN M. AVEY, *Secretary-Treasurer.*

Minutes Annual Meeting 1936-1937 Board of Directors

CHICAGO, JULY 20, 1937.

This, the final meeting of the 1936-1937 Board of Directors, was called to order with President James L. Wick, Jr., presiding. Directors present included E. O. Beardsley, E. W. Campion, W. L. Seelbach, Frank J. Lanahan, Sam Tour, W. J. Cluff, H. S. Washburn, James R. Allan, D. M. Avey, Marshall Post; H. Bornstein, Vice-President.

Others present included C. E. Hoyt, Executive Vice President, R. E. Kennedy, Technical Secretary, Directors-elect Duncan P. Forbes, H. B. Hanley, and Thomas Kaveny; Past-Presidents R. A. Bull and General T. S. Hammond.

Minutes Approved

The Chair announced that the first order of business would be approval of minutes of last meeting and that first would be the minutes of the annual meeting held July 23, 1936 which were printed in full in bound volume of Transactions, No. 44.

On motion of W. L. Seelbach, seconded by H. S. Washburn, the minutes of this meeting were approved without reading.

On motion of E. W. Campion, seconded by W. J. Cluff, the minutes of the Executive Committee held in Chicago, September 30, in Youngstown October 19 and in Chicago, December 4, copies of which have been mailed to all members of the Board, were approved without further reading.

The Chair then called for the reading of the minutes of the special meeting of the Board held in Milwaukee during the annual convention, May 3, 1937 and minutes of adjourned meeting, May 6, 1937. The minutes of these meetings were read by Secretary Avey and on motion, duly seconded, were approved as read.

Officers' Reports

The Chair announced that the next order would be reports of officers. The report of the Executive Vice President was read by Mr. Hoyt and on motion was received, ordered filed with copies of the report to be mailed to the members of the Board.

The report of the Secretary-Treasurer was read by Mr. Avey and on motion of Mr. Lanahan, duly seconded, was ordered filed as read. The petition of the Southern California Chapter, received too late for action at the Milwaukee convention, was approved.

The report of the Technical Secretary was presented by Secretary Kennedy in mimeograph form, ten pages in all and was not read in full

Following Mr. Kennedy's comment on certain sections of his report, it was duly moved and seconded that the report be received and filed as presented.

The Chair announced that next in order would be the report of E. O. Jones, Director of Safety and Hygiene, but in the absence of Mr. Jones, this report would be passed and presented later.

Report of Finance Committee

A summary of the audit of the books of the Treasurer for the year ending June 30, 1937, made by R. T. Pritchard, certified public accountant, Chicago, was presented by Frank J. Lanahan, Chairman of the Finance Committee. Mr. Lanahan submitted a summary and review of the audit as prepared by his own personal auditor, E. W. Wright. On motion of Mr. Washburn, seconded by Mr. Seelbach, it was moved that the audit and the report thereof, presented by Chairman Lanahan, be approved and ordered filed.

Revision of Cast Metals Handbook

A portion of Mr. Kennedy's report previously presented and referring to Handbook revision was presented for action. Following discussion by President Wick, Director Tour presented his views as to the cost of the Non-Ferrous section preparation. He stated that it was estimated by the Non-Ferrous Advisory Committee that the cost of a satisfactory section would range from \$5,000 to \$10,000, and that the division would need clerical help, and that it would take about \$2,500 to cover possible costs for the 1938 revision. President Wick suggested the possibility of the Purchasing Agents Association helping as to financing. Mr. Lanahan opposed this suggestion. Mr. Avey questioned Mr. Tour if the amount was for research or for the collection of existing data. Mr. Bornstein stated that the Handbook revision question should be referred to the Handbook Policy Committee to decide as to the amount of money needed, and to report to the new Board its recommendations. Mr. Campion moved that it be referred to the new Board. Mr. Seelbach seconded. Motion carried.

Alloys of Iron

Director Tour, referring to the portion of Mr. Kennedy's report covering the work of the Alloy Cast Iron Committee, stated that this was a duplication of effort of the work being performed by the Alloy of Iron Research, which he believed has done more than \$2,000 worth of work, already paid for. He called for further study by the A.F.A. relative to its commitments to the Alloy of Iron Research. Mr. Bornstein expressed the thought that the new Board should consider this obligation. Mr. Washburn moved that it be referred to the new Board, Mr. Kennedy to collect information and report on this situation. Motion carried.

To expedite the work of the Board, the following items on the agenda of this meeting were referred to the incoming Board for consideration and action:

- a. Design of steel castings.
- b. Malleable iron shrinkage tests—research.

- c. Molding sands research.
- d. Invitations to participate in the New York World's Fair.
- e. Membership in the American Standards Association.
- f. Communication with the Navy Department.
- g. Milwaukee apprentice theme contest.
- h. Suggested amendments to by-laws permitting local affiliates to membership.

The Chair announced that the next report would be that of the Manager of Exhibits. Mr. Hoyt said the report was long and that as time was limited he would ask the privilege of mailing copies to members of the Board. It was so ordered.

Report of Fact-Finding Committee

President Wick next called for the report of the special Policy and Fact-Finding Committee which he had appointed of which Director and Past-President Lanahan was Chairman, other members being Vice President Bornstein, Directors Marshall Post and Sam Tour; Past-Directors E. H. Ballard and H. S. Simpson. Ex-officio members, James L. Wick, Jr., C. E. Hoyt and Dan M. Avey.

President Wick stated that this committee had held three meetings; the first in Milwaukee, May 6, the second in Pittsburgh, May 24, the third in Chicago, July 19. President Wick stated further that in the interval between meetings there had been a considerable exchange of correspondence, that several special reports had been prepared and submitted for review by each member of the committee. Then, expressing appreciation for the work of this committee, he called on Chairman Lanahan for a report.

Following a general statement of the work of his committee, Chairman Lanahan read a report which he said constituted the minutes of the meeting of the previous day. Summarized, his report contained the following recommendations:

- a. Study and revisions of the objective and responsibilities of A.F.A. as previously declared.
- b. Recommended changes in publication policies.
- c. Revision of membership classes and dues structure to include a new class to be called Sustaining members. The membership in this class to be limited to producers of castings.
- d. Change in percentage of refund of dues to chapters as provided for in the by-laws.
- e. Revision in by-laws authorizing organization by company members of A.F.A. of management or other sections and the preparation of a manual to be approved by the Board of Directors for the conduct of sections, recommending that as a supplement to the four castings divisions adding one on equipment and supplies in which users' interest would predominate.
- f. Preparation of a budget to cover present and proposed new activities.

When he had completed his report, Chairman Lanahan moved that the report be accepted and referred to the new Board and that the Fact-Finding Committee be discharged. The motion was seconded by Mr. Campion and following expressions of appreciation for the splendid work of the

committee by various members of the Board, the motion was unanimously carried.

Report of Election of Officers and Directors

The Secretary reported that at the annual business meeting held in Milwaukee, May 6, 1937, Hyman Bornstein had been duly declared President and Marshall Post, Vice President to serve terms of one year each; and Duncan P. Forbes, C. J. P. Hoehn, James L. Wick, Jr., H. B. Hanley and Thomas Kaveny declared elected Directors to serve terms of three years each. C. E. Sims was declared elected Director to serve the uncompleted term of Marshall Post, his term to expire in 1939. The officers and directors mentioned were announced as taking office immediately following the adjournment of the Board meeting.

Following reading of report, President Wick introduced the new officers. He then called on Directors W. L. Seelbach and E. O. Beardsley, E. W. Campion, Frank J. Lanahan and Sam Tour whose terms as Directors would expire with the adjournment of this meeting. In responding, each expressed the pleasure and satisfaction he had experienced as a Director of A.F.A.

President Wick then in well chosen words expressed the joy that had been his in serving the Association as President.

Mr. Hoyt, addressing the President, requested the privilege of voicing, not only for himself but for all members of the staff, appreciation for the splendid cooperation, helpfulness and enthusiasm of the retiring President.

President Wick then turned the gavel over to Vice President and President-elect Bornstein who declared the final meeting of the 1936-1937 Board of Directors adjourned.

Respectfully submitted,

DAN M. AVEY, *Secretary.*

Minutes First Meeting 1937-1938 Board of Directors

PALMER HOUSE, CHICAGO, TUESDAY, JULY 20, 1937.

The first meeting of the Board of Directors of the American Foundrymen's Association for the fiscal year 1937-1938 was called to order by President Hyman Bornstein. Directors present included W. J. Cluff, H. S. Washburn, James R. Allan, D. M. Avey, Duncan P. Forbes, H. B. Hanley, Thomas Kaveny and James L. Wick, Jr. Officers present in addition to the President were Vice President Marshall Post, Executive Vice President C. E. Hoyt, Technical Secretary R. E. Kennedy and Safety and Hygiene Director E. O. Jones. Past-President R. A. Bull and Past-Director Sam Tour also were present.

Organization of New Board

President Bornstein presiding announced that the first order of business would be to organize the Board in accordance with the provisions

of the by-laws and called for the report of the Nominating Committee which he had appointed at the morning meeting to nominate officers and members of the Executive Committee.

The report was read by Marshall Post, Chairman of the Committee. Mr. Post stated that the Committee recommended that the office of Secretary-Treasurer be combined and so moved. The motion was seconded and carried.

When Mr. Post had completed his report for officers and assistant officers as follows, he moved their election by the Board:

- For Executive Vice President—C. E. Hoyt.
- For Secretary-Treasurer—Dan M. Avey.
- For Technical Secretary—Robert E. Kennedy.
- For Manager of Exhibits—C. E. Hoyt.
- For Director of Safety and Hygiene Section—E. O. Jones.
- For Assistant Secretary-Treasurer—Jennie Reininga.
- For Assistant Technical Secretary—Norman F. Hindle.

The Chair stated that if there were no objections, one ballot would be cast on the report. There being none, this motion was seconded and unanimously carried.

Mr. Post, continuing, submitted the report of the Nominating Committee on the election of four members of the Board to serve with the President, Vice President and Executive Vice President as members of the Executive Committee for the coming year, and nominated H. S. Washburn, J. R. Allan, L. N. Shannon, J. L. Wick, Jr.

On motion by Mr. Forbes, seconded by Mr. Cluff, nominations were declared closed and on motion, duly seconded, the four named directors were elected members of the Executive Committee.

President Bornstein announced that the long established practice of having the President, Vice President and the immediate Past-President act as the Finance Committee of the Board would be continued and he would call on Chairman J. L. Wick, Jr., for the report of the new Finance Committee with recommendations for salaries and compensations for the year beginning July 1, 1937.

On motion by Mr. Washburn, seconded by Mr. Kaveny, the report of the Finance Committee was received. Following a discussion of the report during which time salaried officers of the Association retired from the meeting, the motion to approve salaries and compensations as recommended by them, was approved and authorized.

Disbursement of Funds Resolution

On motion by Mr. Wick, seconded by Mr. Kaveny, all resolutions required by the Harris Trust and Savings Bank for the establishing of accounts and withdrawal of funds was unanimously authorized. It was further resolved that checks for withdrawal of funds, general checking accounts, all interest savings accounts, all securities of the sinking fund of the American Foundrymen's Association shall require the signature of any two of the following officers of the Association: President, Vice President, Executive Vice President and Secretary-Treasurer.

On motion of Mr. Kaveny, seconded by Mr. Allan, the Secretary's expense account of \$1,000 was approved. This money to be used in paying

incidental expenses and reconciled at the end of the each month by a full statement of expenditures, the withdrawal check to be signed by the Secretary-Treasurer, Assistant Secretary-Treasurer or Executive Vice President.

On motion of Mr. Kaveny, seconded by Mr. Cluff, the following resolution was unanimously adopted:

Resolved: The officers of this Association are hereby authorized to open a checking account in the name of the Association in the convention city in 1938 and that the Executive Vice President or the Secretary-Treasurer are hereby authorized to execute the resolutions required by the bank and to determine how this account shall be opened and the signatures for the withdrawal of funds.

On motion by Mr. Wick, seconded by Mr. Allan, it was unanimously voted to continue in effect the resolutions adopted at the last annual Board meeting authorizing the Secretary-Treasurer to reimburse committee members and Board members for traveling expenses at regular called meetings with the exception of such meetings as are held during convention week unless they be specifically authorized by the Executive Committee.

Moved by Mr. Allan, seconded by Mr. Hanley, that funds be made available for apprentice contests prizes at the 1938 convention to the extent of appropriations made available by the Board of Awards from awards interest fund account, and that the Board of Awards be advised of this action and requested to make suitable appropriations.

Committee Appointments.

On motion duly seconded, the President was authorized to appoint all standing and special committees not provided for in the by-laws or by special act of the Board.

The Chair announced that the next order of business would be consideration of the report of the Fact-Finding Committee which had been presented at the previous Board meeting and referred to this Board. Various phases of the report were discussed and then acting upon the recommendation of President Bornstein, it was moved, seconded and carried that the report be referred to the new Executive Committee which would convene early in the fall, and that no action be taken on the report until after the Executive Committee had made their report to the Board of Directors.

Mr. Jones, Director of Safety and Hygiene, who was not present when his report was called for at the morning meeting, read his report at this time, and on motion of Mr. Wick, seconded by Mr. Cluff, the report was received and ordered filed.

Invitations for the 1938 Convention and Exhibit

Mr. Hoyt reported on invitations received for the 1938 convention, submitting a verbal report of inspection he had made of facilities in New York, Atlantic City and Cleveland. Following this report and discussion, Mr. Allan moved that the 1938 convention be held in Cleveland with an exhibit. The motion was seconded by Mr. Kaveny and unanimously carried. Discussion followed as to date of the meeting. Mr. Hoyt reported

on the dates of other conventions that would be held in the spring and would, to a certain extent, conflict.

It was the unanimous opinion of those present that should it be found that all exhibit, convention and hotel facilities were available for the week of May 16, that the convention be held that week with the exhibit opening on the previous Saturday, May 14, continuing through the evening of that day, closed Sunday and open with the convention on Monday morning, May 16.

Alloy Iron Research Fund

The action of the Board of Directors at the annual meeting in Cleveland, July 23, 1936, authorizing the Secretary to address a communication and copy of resolutions to Engineering Foundation setting forth the Association's ideas toward further contribution to Alloy Iron Research Fund was discussed following which Technical Secretary Kennedy was directed to present the history of this case and make recommendations for it after obtaining additional information from Dr. MacKenzie, Mr. Sisco and Mr. Tour.

Handbook Revision

The question of Handbook revision was discussed at length, and the particular need for appropriations for carrying on the work. It was decided that the Policy Committee on Handbook revision make recommendations to the Board as to funds needed and that a meeting of the Committee for determining these needs be held at an early date.

The Secretary read an invitation to A.F.A. to sponsor a foundry and castings exhibit at the New York World's Fair. No action was taken.

Invitation of A.F.A. was presented by Mr. Avey and Mr. Allan, to membership in the American Standards Association. Following a discussion, it was moved that the Secretary be authorized to continue further negotiations with A.S.A.

Request to Permit Chapters to Have Local Affiliates

Mr. Hoyt reported a communication from Past-President G. H. Clamer proposing that the by-laws of the Association be amended to permit local affiliate members of chapters. There appeared to be a unanimous feeling of the members of the Board present that this would not be desirable, and Mr. Hoyt was instructed to so advise Dr. Clamer.

Executive Committee Resolution

Mr. Allan moved the following resolution:

Resolved: That the Executive Committee of this Board be empowered to act for the Board in the interim between Board meetings in all matters requiring Board action.

Resolution seconded and unanimously carried, whereupon President Bornstein declared the first meeting of the 1937-1938 Board of Directors of the American Foundrymen's Association adjourned.

Respectfully submitted,

DAN M. AVEY, *Secretary.*

Minutes of Executive Committee Meeting

CHICAGO, SEPT. 22, 1937.

Members present: President H. Bornstein, Vice President Marshall Post, Executive Vice President C. E. Hoyt, Directors L. N. Shannon, James L. Wick, Jr., James R. Allan, H. S. Washburn.

Others present: Dan M. Avey, Secretary-Treasurer, R. E. Kennedy, Technical Secretary.

President Bornstein introduced a complete redraft of the By-Laws of the Association, embodying amendments made since the adoption in 1934, and also suggested revisions as prepared by President Wick's Fact Finding Committee and assigned to the Executive Committee for consideration by the Board on July 20. Each article and section was studied in detail and approved or revised by the Executive Committee. On motion of Mr. Shannon, seconded by Mr. Allan, the Executive Committee approved of the new form of By-Laws, copies of which will be transmitted to the Board of Directors for their further consideration, revision, amendments and adoption.

On motion of Mr. Washburn, seconded by Mr. Allan, a revised statement of responsibilities of the American Foundrymen's Association was approved similarly for further consideration by the Board.

On motion of Mr. Shannon, seconded by Mr. Washburn, the committee approved a recommended change in publication policy which will divide the bulletin and transactions as at present published bi-monthly. The Transactions embodying papers and proceedings will be published quarterly. A new publication similar in content to the bulletin section of the present Transactions and embracing news of the Association and chapter activities will be published monthly.

To defray anticipated additional cost involved by the foregoing changes in publications, on motion of Mr. Post, seconded by Mr. Washburn, the Executive Committee authorized an increase in publication cost not to exceed \$2,500 for the current year.

The Executive Vice President was requested by the committee to submit a statement of income and expense for the years 1937-38 with budget recommendations.

At the suggestion of Mr. Shannon, the Secretary was instructed to supply each chapter with a breakdown of the attendance registration at the Milwaukee convention so that each chapter may have a list of those in attendance from its area with members designated.

The Secretary reported the decision of the Internal Revenue Department that the American Foundrymen's Association is subject to Social Security taxes although exempt from income taxes. The exemption requested by reason of the status of the Association as a "technical and educational society" has been denied. On motion of Mr. Washburn,

seconded by Mr. Post, the Secretary was authorized to retain counsel and to go to Washington to endeavor to secure a reconsideration.

The Secretary reported that, in accordance with the will of the late Major R. A. Bull, the complete technical library of Major Bull had been made available to the American Foundrymen's Association as a nucleus for a complete library for the foundry industry, and the acceptance of the gift to be on agreement to properly house and make available this library. The Secretary reported that he had accepted the books subject to decision of the Board and that the books had been boxed and delivered to be held subject to this acceptance.

It was pointed out that to accept this library would require securing additional office space, expense of cataloging, recording and attendance. On motion of Mr. Shannon, seconded by Mr. Washburn, the Executive Committee expressed grateful appreciation, but declined the gift.

Mr. Hoyt reported the status of negotiations that had been conducted with Herbert Buckman, Commissioner of the Cleveland Public Auditorium, and Mark Egan, Executive Vice President, Cleveland Convention and Visitors Bureau, covering convention and exhibit facilities for the 1938 annual meeting. He stated that this included the use of three meeting halls at the south end of the Auditorium, two club rooms, a large ballroom and adjacent service rooms, and the Auditorium balcony lounge all at the north end of the main Lakeside Avenue entrance lobby.

Also, for the exhibit purposes, the entire Lakeside Exhibition Hall, upper and lower levels, the Arcade passageway from the main Auditorium and north exhibition halls for exhibits, registration and kindred purposes, these to be available for an over-all three week period including installation, exhibit and removal of exhibits.

Mr. Hoyt stated further that the optional agreements were: (1) an all inclusive service rate, (2) a rate including the use of the halls and an all inclusive service except booths and signs. On motion of Mr. Wick, seconded by Mr. Washburn, the President and the Executive Vice President were authorized to complete negotiations and execute formal agreement.

On motion of Mr. Allan, seconded by Mr. Washburn, the Executive Committee approved the usual rules and regulations for the conduct of A.F.A. exhibits as adapted to conditions that would prevail for the 1938 exhibit.

On motion of Mr. Shannon, seconded by Mr. Wick, the Executive Committee authorized a rate of \$1.00 to \$1.25 per square foot for space, with a premium of 5 to 20 per cent on preferred corner locations, the minimum rate in general to apply to space of greatest depth and the maximum rate to space of shallowest depth.

On the recommendation of Mr. Hoyt, as Manager of Exhibits, it was moved by Mr. Shannon, seconded by Mr. Wick, that the President be authorized to appoint an Advisory Committee on Exhibits to work with the management in determining conditions that should prevail as to hours, etc., contracts or agreements for cartage, etc., which are entered into by the management on behalf of exhibitors.

President Bornstein recommended arranging the annual business meeting to precede an address by some outstanding individual. The intent of this suggestion is to increase attendance at the annual business

meeting. On motion of Mr. Allan, seconded by Mr. Washburn, the Board of Awards was requested to appropriate a sum not to exceed \$300 to defray the expense of securing such a speaker for the next annual meeting.

On motion of Mr. Wick, seconded by Mr. Allan, the committee voted that regional meetings should be scheduled in accordance with recommendations of the Technical Secretary and by approval of the Board.

On motion of Mr. Wick, seconded by Mr. Allan, the President was authorized to appoint a program and papers committee.

It was suggested that the Vice President and Technical Secretary should be given the responsibility of preparing a program for a conference of chapter officers at the annual meeting.

There being no further business, the meeting adjourned.

Respectfully submitted,

DAN M. AVEY, *Secretary-Treasurer.*

Auditor's Report

July 16, 1937.

Mr. James L. Wick, Jr., President
American Foundrymen's Association, Inc.
Chicago, Illinois.

Dear Sir:

I have examined the books of the American Foundrymen's Association, Inc. for the year ended June 30, 1937 and submit herewith the following statements:

- Exhibit A—Balance Sheet, June 30, 1937.
- Exhibit B—Income and Expenses for the year.
- Exhibit C—Surplus, June 30, 1937.
- Schedule I—Award Funds, June 30, 1937.
- Schedule II—Reserve Fund, June 30, 1937.
- Schedule III—Cash Receipts and Disbursements.

The securities comprising the Reserve Fund as shown by the Balance Sheet are stated at cost; the market value thereof at date is \$411.95 in excess of cost.

Similarly the securities comprising the Award Funds (Schedule I) are shown at cost, the market value being \$956.65 in excess thereof.

The attached statements do not take into account any liability for taxes under the Social Security Act. The Internal Revenue Department holds the Association is not exempt from the taxes but this contention is disputed. If such taxes should subsequently be decided to be payable, the tax is estimated to be as follows:

Unemployment Tax—1936	\$ 305.23
Unemployment Tax—1937	390.07
Old Age Pension Tax—1937.....	153.04
	<hr/>
	848.34
Employees Tax Not Deducted.....	153.04
	<hr/>
	\$1,001.38

Subject to these remarks, it is my opinion that the attached statements correctly reflect the condition of the Association as at June 30, 1937 and the results of its operations for the year ended on that date and as shown by the books.

Respectfully submitted,

ROBERT T. PRITCHARD,
Certified Public Accountant.

NOTE: A copy of the Auditor's Balance Sheet is shown on the following page.

BALANCE SHEET AS AT JUNE 30, 1937

ASSETS

ASSOCIATION ASSETS	June 30, 1937
Cash in Bank (Schedule III).....	\$38,523.37
Accounts Receivable, Dues, etc.....	1,668.78
Supplies on Hand.....	1,850.35
Furniture and Fixtures, less Depreciation Reserve.....	1,597.47
Total Association Assets.....	\$43,639.97
RESERVE FUND (Schedule II)	
Investments at Cost.....	\$14,865.55
Cash in Bank on Savings Account.....	1,099.19
Total (Market Value \$16,376.69).....	\$15,964.74
STEEL CASTINGS TEST FUND	
Cash in Bank on Savings Account.....	\$ 322.84
Grand Total	\$59,927.55

LIABILITIES

ASSOCIATION LIABILITIES	June 30, 1937
Unpaid Bills	—0—
Dues Paid in Advance.....	\$ 3,147.45
Unexpended Appropriation for Sand Research.....	381.07
Other	—0—
Total Association Liabilities.....	\$ 3,528.52
Surplus—Exhibit C	40,111.45
	\$43,639.97
RESERVE FUND (Schedule II)	
Principal of the Fund.....	\$15,964.74
	\$15,964.74
STEEL CASTINGS TEST FUND	
Unexpended Appropriation	\$ 322.84
Grand Total	\$59,927.55

Properties of Fully Annealed and Heat Treated Malleable Irons

R. SCHNEIDEWIND¹ and A. E. WHITE,² ANN ARBOR, MICH.

Abstract

A study was made on the properties of malleable iron in the fully annealed and in two heat treated (quench and draw) conditions. The purpose of the investigation was two-fold, namely, to determine whether quick-anneal white irons for malleablizing could successfully be purchased on the basis of a chemical specification and secondly, to present rather complete physical property data for the designing engineer.

It was found that three irons purchased on chemical specification varied somewhat with regard to the rate of breakdown of the cementite, but the tensile values and moduli of elasticity of the three irons showed quite fair agreement.

The properties in tension, compression, torsion, bending, fatigue, impact and hardness were determined at room temperature. The results of the irons in the heat treated condition showed strengths which should prove attractive for many types of service. The torsion properties, due to the presence of temper carbon, are not too favorable, however. Tension and impact were determined at 400° and 800°F.

The microstructures of the quenched and drawn samples showed a spheroidized matrix which was compared with the pearlitic structure obtained by slowly cooling through the critical. The effects of a few alloys on the structure of slowly cooled irons are shown by photomicrographs.

^{1,2} Research Engineer and Director, respectively, Department of Engineering Research, University of Michigan.

NOTE: This paper was presented before the Malleable Iron Division Session of the Annual Convention, Milwaukee, Wis., May 4, 1937.

INTRODUCTION

1. Normal malleable iron as made in the United States is produced by fully annealing white cast iron. The free or massive cementite and the eutectoid cementite are thus completely decomposed and the resulting material is made up of ferrite and temper carbon.

2. For a considerable time foundrymen and metallurgists have been interested in the problem of decreasing the rather long time necessary for completely annealing. It is well known that an increase in silicon is a potent factor in accelerating the decomposition of cementite. Also superheat of the molten iron has been shown to reduce the time necessary for malleabilization.

3. In addition to this effect, superheat also makes possible the use of higher silicon contents without the production of a mottled structure. In fact, good white irons can be cast in sections up to $\frac{7}{8}$ -in. in thickness containing 2.7 per cent carbon and 1.7 per cent silicon. For such an extreme analysis, however, the nature of the charge, the superheat, and the proper general foundry conditions must be carefully maintained.

4. Quick anneal malleable iron apart from the advantages to the maker due to the short graphitizing cycle does not offer any appreciable advantages in physical properties to the user. Considerable interest has been manifested for several years in partially annealed or specially heat treated malleable irons. Some varieties have been called pearlitic malleable and others have even been termed steels. A quick anneal composition is especially attractive for such irons. The claims made for such materials have frequently been based upon the results of a few tensile bars.

5. It was considered important first, to determine whether irons of the quick anneal class, suitable for heat treating as well as for complete malleabilizing could be purchased on specification; and secondly, to investigate rather extensively the physical properties after various thermal treatments.

THREE SECTIONS OF INVESTIGATION

6. The work in this investigation was divided into three sections.

(a) Sets of tensile test bars were purchased upon chemical specification from three different foundries. Portions of

each set were given three different heat treatments of which one was a complete anneal. The tensile properties were determined.

(b) The second portion of the work consisted in obtaining several series of test specimens of different shapes from one of these foundries and determining the physical properties after the same three heat treatments used before. The properties investigated consisted of the following:

- | | |
|---------------------------|------------------------------|
| (1) Tension | (6) Impact |
| (2) Compression | (7) Hardness |
| (3) Torsion | (8) Tension and impact prop- |
| (4) Transverse or bending | erties at 400 and 800°F. |
| (5) Fatigue | (9) Microstructure |

Moduli were obtained on items 1 to 4, inclusive.

(c) The third portion of this work consisted in determining the same physical properties after similar or identical heat treatments on similar irons containing 0.5 per cent molybdenum.

CHEMICAL COMPOSITIONS

7. The following chemical specification was submitted to three foundries which will be designated as *I*, *II*, and *III*:

<i>Element</i>	<i>Per Cent</i>
Carbon	2.3 to 2.4
Silicon	1.4 to 1.5
Sulphur	under 0.05
Manganese	under 0.5
Phosphorus	under 0.10

The superheating temperature was to be 2900°F. and the pouring temperature 2750°F. The nature of the charge, the characteristics of the molding sand, and other features of the melting and casting process were left to the discretion of the makers.

8. All three manufacturers used an indirect arc electric melting furnace.

9. Foundry *I* used as their raw material cupola remelt with sufficient steel additions to obtain the desired carbon and silicon contents. Foundry *II* made a synthetic iron from scrap high silicon steel used for electrical purposes, pig iron and ferrosilicon.

Foundry *III* used silvery pig and steel scrap. The analyses of the irons supplied are as follows:

Foundry	<i>I</i>	<i>II</i>	<i>III</i>
Carbon, per cent.....	2.35	2.33	2.30
Silicon, per cent.....	1.42	1.50	1.70
Manganese, per cent.....	0.23	0.28	0.50
Sulphur, per cent.....	0.06	0.030	0.050
Phosphorus, per cent.....	0.05	0.032	0.050

The bars from foundry *III* contained higher silicon than specified because these were a part of a regular production iron.

10. The bars for the second and third portions of the work were supplied by foundry *III*. The carbon content was 2.45 per cent and the silicon 1.46 per cent. The irons containing molybdenum analyzed 2.51 per cent carbon, 1.40 per cent silicon and 0.49 per cent molybdenum.

HEAT TREATMENT

11. The white iron test bars in the preliminary survey were heat treated at the University. Three different heat treatments were given to portions of each batch of iron.

12. Heat treatment *A* consisted of heating for 15 hours at 1700°F., cooling to 1525°F. in two hours. The specimens were then oil quenched and tempered for two hours at 1325°F.

13. Heat treatment designated *B* consisted in heating at 1700°F. for 15 hours, cooling to 1525°F. in two hours, and oil quenching. The time of tempering in this case was four hours.

14. Heat treatment *C* was a complete anneal which consisted in heating at 1700°F. for 15 hours, cooling to 1325°F. in three hours and holding at this last temperature for 20 hours. It was found by metallographic examination on some preliminary work that the irons from the three foundries varied somewhat in annealing characteristics. It is for this reason that this 38 hour anneal was used. The irons of foundry *III* could have been completely annealed in 24 to 28 hours. It was found that a few of the specimens from Foundry *I* did not anneal completely free from carbides, although they were almost completely annealed. Similar heat treatments were conducted at a commercial heat treating establishment on the irons from foundry *III* which were used in the second and third parts of the investigation. Due to the fact that the specimens were of various sizes and shapes their

annealing rates were different from those of the tensile bars because of different rates of cooling in the mold. In addition, in the case of the irons containing 0.5 per cent molybdenum it was found necessary to increase the annealing time from 10 to 15 per cent.

15. The bars were machined to suitable dimensions and tested, as will be described in detail.

MARKINGS

16. In order to facilitate identification of the various irons after the heat treatments, the following system of designation was used. The first symbol indicates the foundry or batch of iron. For example II means the iron was made by foundry II and Mo means that the iron contained molybdenum. The second symbol refers to the heat treatment so that iron IIIA was made at foundry III and was quenched followed by a two hour draw; iron MoC is a fully annealed iron containing molybdenum.

TENSILE PROPERTIES

Visual Inspection

17. The test bars furnished by foundry III seemed sound and had a very satisfactory smooth surface. Those furnished by foundry I showed a satisfactory surface, although not so good as those from foundry III. The bars from foundry II showed surface defects, small pin holes in the shoulder between the grips and the reduced section of the pieces. The surface flaws in these irons were explained to the writer by a representative who saw these irons poured as being due to too high a pouring temperature. Evidently, the specification had not been followed in this respect.

18. In order that the tensile tests should be conducted in as accurate a manner as possible and to facilitate the determination of moduli of elasticity it was necessary to adopt a modification of the standard A.S.T.M. test bar. Although the usual friction gripping in the test machine is sufficient for ordinary tensile testing, a threaded grip is necessary in determining the modulus.

19. It was decided after conferring with a group of malleable iron metallurgists that the ends of the test bars be made 1/16 in. larger in diameter to permit threading. In all other respects the tensile bars conformed to the A.S.T.M. standard.

Tensile Properties

20. The physical properties in tension were determined in an Amsler hydraulic testing machine. The bars containing molybdenum were not threaded since no modulus of elasticity measurements were contemplated. Due to the fact that cast test bars naturally have rough surfaces and are apt to be out of round so that it is difficult to obtain the true diameter, about one in six were fully machined. The results obtained from machined bars did not differ greatly from those which were not machined and the "skin effect" often reported was not found in this investigation.

21. The modulus of elasticity is most accurately measured on an 8 in. gage length by means of Martens mirrors. Since the malleable iron test bars have been standardized, a 2 in. gage length was used in order to avoid possible criticism because of non-standard test specimens.

22. The stretching of the specimen under load was measured to 0.0001 in. by means of a special extensometer. Readings were taken at 500 lb. increments of load to beyond the proportional limits. The extensometer was then removed and the loading was carried on in the usual manner. The yield point, ultimate strength, and elongation were determined and the modulus of elasticity was calculated.

23. The results of the individual tests are given in Tables 1, 2, 3 and 5.

24. Foundry I supplied more test bars than had been requested. For this reason, two bars were given the usual heating at 1700°F. and oil quench from 1525°F. Two bars were tempered for one hour at 1325°F. and two bars were tempered 8½ hours at 1325°F. The results are given in Table 4 in which the averages of the two and four hour draws are repeated for purposes of comparison.

25. The comparative results of irons from the foundries I, II, and III indicate that fair uniformity in properties may be expected on a given specification. The iron from the foundry I has slower annealing characteristics so that if the time of drawing or annealing had been lengthened for this iron, almost identical results would have been obtained as for the irons from foundry III.

Compression Properties

26. The physical properties in compression were determined

in an Amsler hydraulic testing machine. The specimens were machined 1.5 in. long and 0.75 in. in diameter. Load was applied until the curve plotted in the machine deviated from a straight line. This point was considered the yield point. The load which caused a deformation of 2 per cent of the total length was also recorded. Tests could not be conducted to fracture because the specimens buckle and bend.

27. The irons containing molybdenum in all cases were stronger than those without molybdenum. It is interesting to note that the yield point in compression is fairly close to that in tension. The results are given in Table 6.

Torsion Properties

28. The torsion tests were conducted in an Olsen torsion testing machine of 240,000 inch-pound capacity. The specimens were machined to an 18 in. length and 0.9 in. diameter from bars cast 18 in. long and 1 in. in diameter. The gage length used was 8.25 in. The stress was applied in inch-pounds. The twist was measured by means of a goniometer and indicator placed at opposite

Table 1

TENSILE PROPERTIES OF MALLEABLE IRONS

Heat Treatment A—1750°F.—1525°F.—oil quench—2 hour draw at 1325°F.

No.	III	Yield Point lb. per sq. in.	Tensile Strength lb. per sq. in.	Elongation %	Modulus of Elasticity lb. per sq. in.	B. H. N.
7	1a	60,200	74,100	6.5	25,300,000	
8	2	61,000	75,500	7.0	25,850,000	
9	3	60,800	80,000	6.5	25,700,000	231
10	4	57,800	72,600	7.0	24,800,000	
12	5	62,000	77,300	6.0	24,800,000	
13	6	60,200	77,400	6.0	26,400,000	
Average		60,300	76,150	6.5	25,475,000	
	I					
54	1	68,300	84,800	5.0	25,600,000	
55	2b	65,200	74,500	2.5	25,400,000	
56	3	64,400	81,700	5.0	25,450,000	234
57	4	65,700	83,100	6.0	25,350,000	
58	5	69,500	89,200	6.5	25,300,000	
59	6	66,000	79,500	5.5	26,500,000	
Average		66,620	82,660	5.6	25,600,000	
	II					
49	1	63,800	78,900	5.0	24,300,000	
50	2c	61,100	73,000	3.5	24,800,000	
51	3	60,400	78,950	7.0	25,250,000	248
52	4	60,600	72,500	5.0	25,300,000	
53	5a	65,000	88,800	9.0	25,600,000	
	—	—	Broke before annealing —	—	—	—
Average		60,180	79,230	5.9	25,050,000	

a—Machined.

b—Broke at shoulder.

c—Broke at shoulder—defective.

Table 2

TENSILE PROPERTIES OF MALLEABLE IRONS

Heat Treatment B—1750°F.—1525°F.—oil quench—4 hour draw at 1325°F.

No.	III	Yield Point lb. per sq. in.	Tensile Strength lb. per sq. in.	Elongation %	Modulus of Elasticity lb. per sq. in.	B. H. N.
11	1a	50,250	65,750	9	25,700,000	
16	2b	50,200	65,200	7.5	25,000,000	
17	3	51,200	66,300	9	26,000,000	183
18	4	48,900	62,500	8.5	24,500,000	
19	5	50,000	64,200	8.5	25,650,000	
20	6	49,700	62,700	8	25,600,000	
Average		50,042	64,442	8.4	25,408,333	
—Machined. b—Forms defect above gage mark.						
I						
29	1	55,300	75,000	7.5	25,750,000	
30	2	53,750	73,450	7.5	24,950,000	
31	3	56,300	74,900	6.5	24,700,000	225
32	4	49,800	66,600	6.5	25,600,000	
33	5a	53,000	63,100	2.5	25,750,000	
34	6b	45,500	60,000	5.5	25,800,000	
Average		52,730	68,842	6.7	25,425,000	
a—Broke at gage mark—defect. b—Machined.						
II						
23	1a	47,750	67,500	8	24,500,000	
24	2b	47,800	65,000	7	24,400,000	
25	3c	46,500	56,500	3	25,300,000	206
26	4	46,900	66,700	6.5	26,800,000	
27	5d	49,900	57,600	4.5	25,300,000	
28	6e	46,500	65,000	3.5	25,000,000	
Average		47,225	63,150	6.5	25,216,667	
a—Machined. b—Flaw at surface at break. c—Broke at flaw near shoulder outside of gage mark d—Pitted surface. e—Broke outside of gage marks.						

Table 4

IRONS FROM FOUNDRY I

Heat Treatment—1750°F.—1525°F.—oil quench—1325°F. draw

Drawing Time, Hrs.	Yield Point lb. per sq. in.	Tensile Strength lb. per sq. in.	Elongation %	Modulus of Elasticity lb. per sq. in.
1	63,500	87,300	4.0	26,000,000
1	64,333	83,800	3.5	25,750,000
2 (avg.)	66,620	82,660	5.6	25,625,000
4 (avg.)	52,730	68,842	6.7	25,425,000
8½	45,700	60,500	12.0	24,800,000
	45,000	57,300	9.0	24,400,000

ends of the gage length and was measured in inches to an accuracy of 0.01 in. The arm length of the goniometer indicator was 11.5626 in. so that the twist of the shaft was greatly magnified. When the yield point was reached the goniometer was removed and the angle of twist was read directly on another scale on the basis of a 12 in. gage length.

29. The formula for the determination of the modulus of elasticity is

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{\frac{T_a}{J}}{\frac{\Delta}{l}}$$

Table 3

TENSILE PROPERTIES OF MALLEABLE IRONS

Heat Treatment C—Full Anneal

No.	III	Yield Point lb. per sq. in.	Tensile Strength lb. per sq. in.	Elongation %	Modulus of Elasticity lb. per sq. in.	B. H. N.
37	1	35,200	52,000	16.5	25,050,000	
38	2	37,050	51,000	8a	24,000,000	
39	3	37,100	53,200	16	26,300,000	133
40	4	38,100	54,000	13.5	25,100,000	
41	5	37,500	51,400	14.5	25,000,000	
42	6	38,000	50,750	13.5	25,050,000	
Average		37,325	52,058	14.8	25,072,667	
a—Flaw.						
	I					
1	1	37,800	58,300	12.5	24,400,000	
2a	2	41,000	57,750	9.0	24,100,000	
3b	3	33,900	57,400	—	24,400,000	160
4c	4	40,300	49,750	11.0	24,900,000	
5	5	40,600	62,300	8.0	25,600,000	
6	6	35,600	58,300	9.0	25,100,000	
Average		38,200	57,300	9.9	24,750,000	
a—Machined. b—Broke in fillet. c—Flaw.						
	II					
43a	1	35,000	48,750	11	24,590,000	
44	2	33,400	46,500	8	24,600,000	145
45	3	33,000	47,000	8	25,400,000	
46	4	33,800	45,700	8	24,400,000	
47b	5	34,100	49,800	13.5	24,200,000	
48	6	33,500	47,900	8	24,200,000	
Average		33,800	47,442	9.4	24,565,000	

a—Machined. b—Only good bar that broke with black fracture and between gage marks.

where T = torque in inch-pounds

J = section moment

a = radius in inches

Δ = total deformation in radians

l = gage length in inches

This simplifies as follows:

$$E = \frac{2 \times \text{unit load} \times \text{gage length} \times \text{radius of indicator}}{3.1416 \times \text{unit deformation} \times (\text{radius of specimen})^4}$$

30. The shearing stress is calculated according to the formula

$$S_s = \frac{16T}{\pi d^3} \text{ where } T \text{ is torque in inch-pounds and } d \text{ is the diameter}$$

of the bar in inches. The stresses at the proportional limit, the yield point and for the point of rupture were thus calculated from the test data.

31. All of the bars were tested in the same manner and the properties calculated as shown. In some instances bad flaws impaired the shearing strength for rupture and the total twist but usually such flaws did not greatly disturb the values for stresses in the elastic range such as E , elastic limit, and yield point.

Table 5

TENSILE PROPERTIES OF MALLEABLE IRONS CONTAINING 0.5% MOLYBDENUM

Iron	Yield Point lb. per sq. in.	Ultimate Strength lb. per sq. in.	Elongation per cent in 2 inches	B H N
	72,500	75,900	2.5a	
	69,000	75,300	4.0	
MoA	68,800	75,600	3.5	245
	68,700	78,300	2.5	
	70,100	79,200	4.0	
	73,300	82,400	3.5	
Avg.	70,567	77,793	3.5	
MoB	69,000	71,200	7.0	
	65,300	75,600	7.5	
	64,300	70,000	9.0	223
	66,300	72,700	7.5	
	68,700	78,600	8.5	
	66,100	77,400	8.0	
	66,400	73,800	8.0	
	62,600	72,400	7.5	
Avg.	64,962	73,962	7.9	
MoC	35,100	52,800	13.5	
	37,150	55,200	12.5	
	34,100	57,300	17.0	
	38,900	53,500	16.5	130
	38,200	54,250	14.0	
	39,900	54,000	17.0	
Avg.	37,225	54,485	15.1	
a—Flaw.				

32. The values obtained in the individual tests are given in Tables 7 and 8. For purposes of comparison a few values for the torsional modulus are given here:

Steel	11,500,000 lb. per sq. in.
Cast Iron	6,000,000 lb. per sq. in.
Aluminum	3,630,000 lb. per sq. in.
Brass	5,380,000 lb. per sq. in.
Bronze	6,000,000 lb. per sq. in.

Bending or Transverse Properties

33. The physical properties in bending were determined in an Amsler hydraulic testing machine. The specimens were ma-

Table 6
COMPRESSION PROPERTIES

Iron	Yield Point lb. per sq. in.	Stress at 2% deformation lb. per sq. in.	Diameter Inches
III A	61,500	67,300	0.750
	56,600	66,900	0.751
	64,600	74,850	0.750
	57,200	74,000	0.750
	59,260	70,050	0.750
Avg.	59,832	70,600	0.750
III B	56,300	65,250	0.750
	56,400	64,300	0.750
	59,000	68,500	0.750
	59,400	67,300	0.750
	57,750	69,000	0.750
Avg.	57,770	66,870	0.750
III C	34,200	56,200	0.748
	36,200	45,600	0.748
	28,250	52,100	0.750
	32,300	57,700	0.750
Avg.	35,488	52,900	0.749
MoA	75,100	110,600	0.751
	81,200	108,800	0.751
	80,300	114,600	0.751
	79,600	109,500	0.751
Avg.	79,050	110,875	0.751
MoB	76,200	107,000	0.751
	76,700	107,100	0.750
	76,500	105,300	0.751
	79,300	100,300	0.750
Avg.	77,175	104,925	0.750
MoC	44,700	82,600	0.749
	44,200	83,250	0.749
	46,800	78,600	0.750
	39,250	78,700	0.750
Avg.	48,787	81,037	0.750

chined 16 in. long, about 1.4 in. deep and 0.5 in. wide, from bars cast 16 in. long, 1.5 in. deep and 0.625 in. wide. A span of 14 in. was selected because this is standard for cast iron arbitration bars. The load was applied midway between. The supports and the deflection was measured directly below the point of loading by means of a lever and an Ames dial. Deflection was measured to 0.0001 in. When the yield point was reached, the Ames dial was removed and deflection was measured directly with calipers and scale.

34. The formula for determining the modulus of elasticity is

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{1}{48} \frac{Pl^3}{\Delta I} \text{ where}$$

P=unit load in pounds

l=length of span in inches

Δ =unit deflection in inches

I=the section modulus = $\frac{1}{12} bd^3$

b=breadth of specimen in inches

d=depth of specimen in inches

$$\text{Hence } E = \frac{12}{48} \frac{Pl^3}{\Delta bd^3} = \frac{Pl^3}{12 \Delta bd^3}$$

The data were plotted to obtain stress strain curves.

Table 7
TORSION PROPERTIES
Shearing Stress

No.	Torsion Modulus of Elasticity lb. per sq. in.	Shearing Stress		Rupture lbs. per sq. in.	Breaking Load in.—lbs.	Angle of Twist at Rupture; degrees in 12 gage length
		Proportional Limit lb. per sq. in.	Yield Point lb. per sq. in.			
III A	7,580,000	31,700	40,600	64,600	6,700	252
	7,840,000	27,400	35,700	64,000	8,425	254
	7,450,000	27,100	35,800	55,200	7,850	150
	8,140,000	30,000	35,500	53,500	7,300	196
	7,410,000	26,600	34,800	59,500	7,225	329
Avg.	7,684,000	28,560	36,480	59,320	7,500	228
III B	7,720,000	27,300	45,500	67,400	7,400	276
	7,790,000	27,000	41,800	62,400	7,750	173
	7,345,000	26,400	33,100	59,200	7,350	276
	7,575,000	26,700	35,800	60,300	7,925	396
	7,230,000	26,500	36,200	53,200	7,435	290
Avg.	7,532,000	26,780	38,520	60,500	7,572	262
III C	7,560,000	9,250	15,500	37,700	6,000	635
	7,020,000	9,000	12,000	34,200	5,600	472
	7,200,000	13,500	16,150	35,300	4,850	467
	7,410,000	13,440	17,150	40,900	5,250	419
	7,300,000	10,600	15,150	37,200	3,500a	57a
Avg.	7,172,000	11,168	15,690	37,080	5,233	453

a—Bad Flaw in specimen.

Table 8
TORSION PROPERTIES

No.	Torsion Modulus of Elasticity lb. per sq. in.	Shearing Stress		Rupture lbs. per sq. in.	Breaking Load in.—lbs.	Angle of Twist at Rupture; degrees in 12" gage length
		Proportional Limit lb. per sq. in.	Yield Point lb. per sq. in.			
MoA	9,970,000	36,600	44,800	53,200a	6,500a	0.5a
	9,130,000	37,500	45,000	47,400	6,950a	0.4
	9,000,000	37,400	44,600	69,800	9,750	134
	10,150,000	38,200	45,200	70,100	9,800	125
Avg.	9,562,500	37,425	44,900	69,950	9,775	130
MoB	9,660,000	30,300	38,400	61,800	7,600	304
	9,100,000	28,500	39,600	51,700a	5,500a	0.5
	9,020,000	34,600	42,600	65,700	4,700	88
	9,250,000	29,600	39,300	62,000	7,500	225
Avg.	9,480,000	30,750	39,950	63,167	6,600	184
MoC	8,010,000	14,250	17,700	42,600	5,900	366
	8,090,000	17,380	21,000	54,400	7,750	560
	8,260,000	15,290	20,050	50,600	7,500	420
Avg.	8,120,000	15,640	19,583	52,533	7,050	401

a—Bad flaw in specimen.

Table 9
BENDING PROPERTIES

No.	Modulus of Elasticity lb. per sq. in.	Proportional Limit lb. per sq. in.	Yield Point lb. per sq. in.	Breaking Load lbs.	Modulus of Rupture lb. per sq. in.	Maximum Deflection inches	Depth d, inches	Width b, inches
III A	23,460,000	64,300	85,000	5,600	128,200	0.73	1.351	0.500
	22,900,000	60,200	83,300	5,660	131,100	1.063	1.363	0.487
	22,600,000	64,700	85,000	5,980	138,100	1.200	1.353	0.495
	23,800,000	60,000	87,500	5,710	131,100	1.010	1.360	0.494
	22,500,000	63,500	81,600	5,610	127,200	1.020	1.360	0.501
	23,100,000	59,700	87,200	5,710	131,500	0.963	1.353	0.498
Avg.	23,060,000	62,066	84,933	5,716	131,200	0.998	1.356	0.496
III B	22,000,000	46,500	76,000	5,450	115,000	0.929	1.429	0.488
	21,800,000	47,000	70,600	5,585	116,100	1.002	1.432	0.500
	22,200,000	48,400	70,600	5,685	114,600	0.873	1.443	0.500
	21,700,000	55,000	76,100	5,550	117,800	0.852	1.432	0.482
	22,300,000	51,300	73,400	6,130	125,600	1.190	1.430	0.500
	22,000,000	47,200	73,500	5,800	119,900	1.302	1.430	0.496
Avg	22,000,000	49,233	73,367	5,700	118,167	1.025	1.433	0.494
III C	17,450,000	25,500	45,800	3,680	70,500	2.55	1.429	0.536
	16,780,000	27,600	47,000	3,590	71,000	2.83	1.435	0.517
	17,200,000	29,600	46,000	4,600	85,000	2.00	1.480	0.517
	17,800,000	31,800	46,800	3,960	80,700	1.80	1.430	0.504
	18,000,000	28,500	45,900	4,050	81,500	2.10	1.430	0.510
	17,950,000	29,500	46,200	4,000	81,300	2.15	1.424	0.508
Avg.	17,530,000	28,750	46,283	3,980	78,333	2.24	1.421	0.520

35. The formula for determining stress in a beam of this type is

$$S = \frac{Mc}{I} \text{ where}$$

S = stress in pounds per square inch

$$M = \text{bending moment} = \frac{1}{4}Pl$$

$$\frac{I}{c} = \text{section modulus} = \frac{1}{6}bd^2$$

$$\text{Hence } S = \frac{Pl}{4} \times \frac{6}{bd^2} = \frac{3Pl}{2bd^2}$$

The stress at the proportional limit and yield point was so calculated.

36. The breaking load was recorded, but a similar calculation cannot strictly speaking be used for determining the ultimate breaking strength because the formulae are based on the assumption of pure elasticity. The values are rigidly true for proportional limit; for the yield point, they are slightly in error, because of the plastic deformation which has taken place.

37. The values obtained for the individual bars tested are given in Tables 9 and 10. It is interesting that in the fully annealed condition the irons containing molybdenum are more rigid, that is, they have a higher modulus and also they have greater strength for about the same amount of deflection. The greater strength of the molybdenum irons in the heat treated condition is probably partly intrinsic in the iron and partly due to the fact that molybdenum retards graphitization and hence for a given length of time of treatment they will be annealed less than an iron not containing molybdenum.

Fatigue Properties

38. Specimens were cast in the form of bars 6 in. long and 0.75 in. in diameter. Standard fatigue specimens were machined. The endurance limit was obtained in a Moore type rotating beam machine. The results are given in Table 11.

Impact Properties

39. These properties were determined on key-hole specimens in a Charpy machine. Since the values were obtained not only at room temperature but also at elevated temperatures the results

Table 10

BENDING PROPERTIES

No.	Modulus of Elasticity	Proportional Limit	Yield Point	Modulus of Rupture				
	lb. per sq. in.	lb. per sq. in.	lb. per sq. in.	Breaking Load lbs.	lb. per sq. in.	Maximum Deflection inches	Depth d, inches	Width b, inches
MoA	24,500,000	83,000		6,690	146,200	0.517	1.387	0.500
	25,210,000	80,800		5,035	142,000	0.358	1.228	0.495
	24,600,000	81,200		6,490	131,000	0.460	1.420	0.515
	23,950,000	79,600		6,185	134,000	0.421	1.400	0.495
	24,750,000	81,300		6,280	144,000	0.395	1.356	0.498
Avg.	24,202,000	81,180		6,136	139,440	0.430	1.364	0.500
MoB	23,800,000	64,000	86,500	6,590	139,800	0.637	1.407	0.498
	23,830,000	68,000	97,700	5,680 _a	121,000 _a	0.324 _a	1.404	0.501
	23,900,000	66,500	95,800	6,590	136,900	0.640	1.410	0.508
	23,600,000	63,300	97,000	6,170	130,000	0.513	1.403	0.505
	23,500,000	60,300	95,100	6,115	132,900	0.458	1.398	0.495
	24,100,000	66,000	93,000	6,470	138,000	0.560	1.400	0.503
Avg.	23,638,333	66,183	94,183	6,381	135,520	0.561	1.404	0.501
MoC	21,500,000	37,700	48,200	4,525	92,900	1.58	1.426	0.504
	22,000,000	39,100	49,400	4,625	95,300	1.65	1.427	0.501
	21,100,000	37,400	46,700	4,390	90,500	1.47	1.429	0.500
	21,100,000	35,900	47,800	4,325	86,300	1.57	1.436	0.511
	22,000,000	36,500	47,500	4,400	89,000	1.56	1.432	0.506
Avg.	21,660,000	37,330	47,920	4,453	91,000	1.56	1.428	0.514

a—Bad flaw in specimen.

Table 11

FATIGUE PROPERTIES OF MALLEABLE IRON

Iron	Endurance Limit lbs. per sq. in.
III A	30,500
III B	26,800
III C	22,100
MoA	31,350
MoB	28,100
MoC	23,000

will be fully described in the section devoted to high temperature tests.

Hardness

40. The hardness values were given along with the tensile properties. It can be seen that in malleable irons there is a rough relationship between the Brinell hardness and the tensile strength as is also the case with steels.

High Temperature Properties

41. The tensile properties were determined by Dr. C. L. Clark, of the University of Michigan, at 400° F. and at 800° F. in accordance with standard procedure for short-time testing.

42. The impact properties were also determined at room temperature, at 400° F., and at 800° F. A series of specimens were heated at 400° F. for 30 minutes and cooled in the air to 80° F.; another series were heated to 800° F. and similarly cooled. The results are given in Tables 12 and 13. The tensile results at room temperature have been repeated for purposes of comparison.

Table 12**HIGH TEMPERATURE TENSILE PROPERTIES**

Iron	Tensile Strength, lb. per sq. in.			Proportional Limit, lb. per sq. in.			Elongation Per Cent		
	80° F.	400° F.	800° F.	80° F.	400° F.	800° F.	80° F.	400° F.	800° F.
III A	76,150	74,725	65,788	39,040	33,750	20,000	6.5	4.1	6.7
III B	64,442	62,088	59,075	30,152	24,150	13,750	8.4	6.3	8.2
III C	52,058	48,188	44,580	18,000	13,750	11,670	14.6	8.2	10.0
MoA	77,783	77,788	76,612	—	40,000	29,170	3.5	1.4	2.8
MoB	73,962	73,836	73,837	—	38,340	22,500	7.9	2.4	3.6
MoC	54,485	52,962	45,650	—	17,500	13,750	15.1	3.0	5.5

Table 13**CHARPY IMPACT PROPERTIES AT ROOM AND ELEVATED TEMPERATURES**

Iron	Impact—Foot Pounds			400° F.	800° F.
	80° F.	400° F.	800° F.	Cooled to 80° F.	Cooled to 80° F.
III A	7.8	8.2	6.3	6.9	7.8
III B	8.9	9.4	7.3	8.8	9.5
III C	11.3	10.5	8.3	11.8	12.5
MoA	4.0	4.3	3.3	4.0	3.9
MoB	5.0	6.2	5.0	6.5	6.0
MoC	10.0	9.7	7.0	11.8	11.5

Metallographic Examination

43. Metallographic examination was made on many specimens. In general, there was very little difference from sample to sample for any given heat treatment. The photomicrographs A and B of Fig. 1 show at magnifications of 100 and 1000 diameters the structure of the irons as cast. Photomicrographs A and B of Fig. 2 show the structure obtained in heat treatment A, the 2-hour draw, and the photomicrographs of Fig. 3 show the structure from

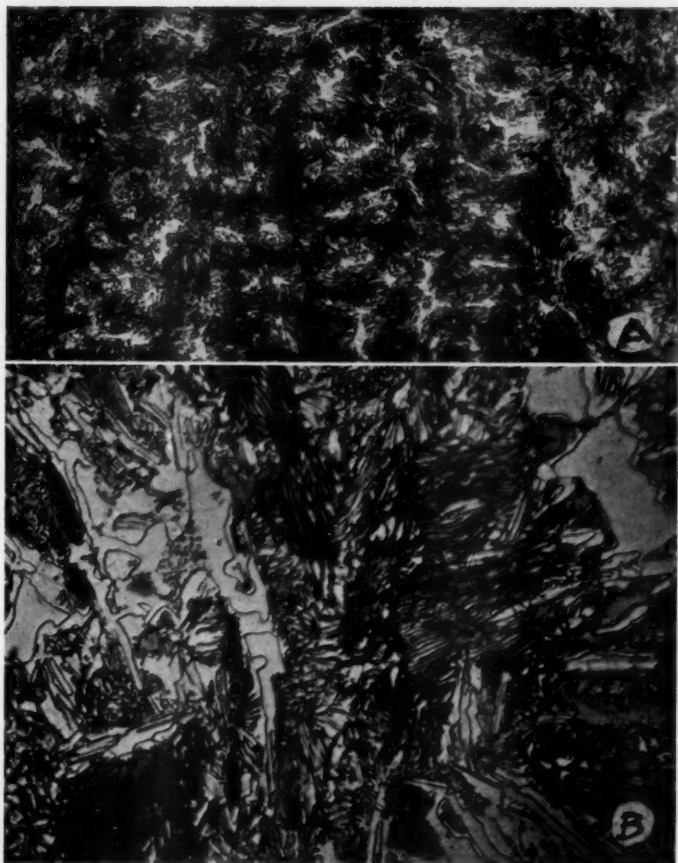


FIG. 1—TYPICAL SECTION OF THE WHITE IRONS AS CAST—(A) X100, ETCHED, (B) X1000, ETCHED.

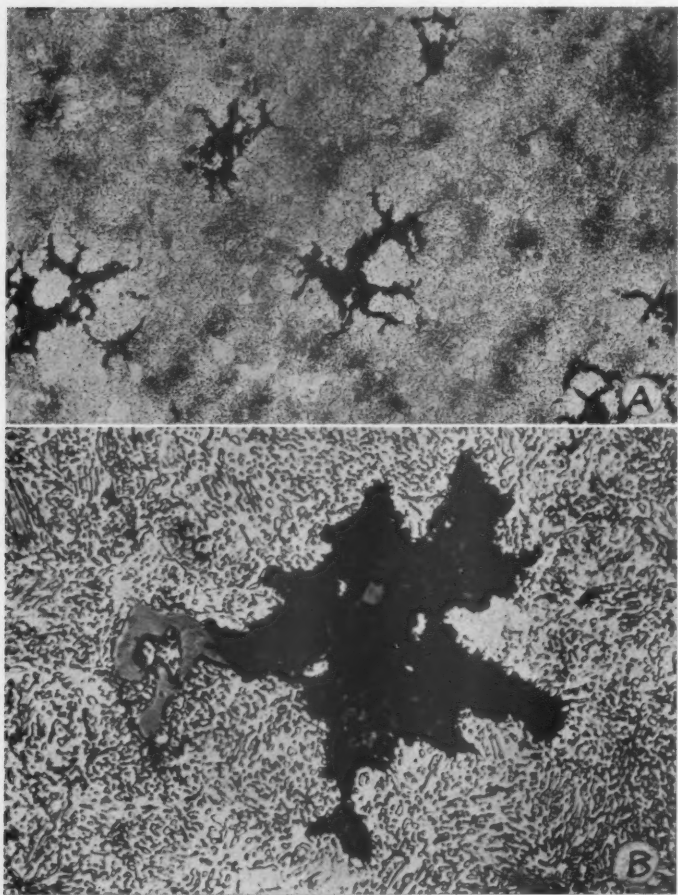


FIG. 2—TYPICAL SECTION OF SPECIMENS III A, QUENCHED IN OIL FROM 1525° F. AND DRAWN FOR 2 HOURS AT 1325° F.—(A) X100, ETCHED, (B) X1000, ETCHED.

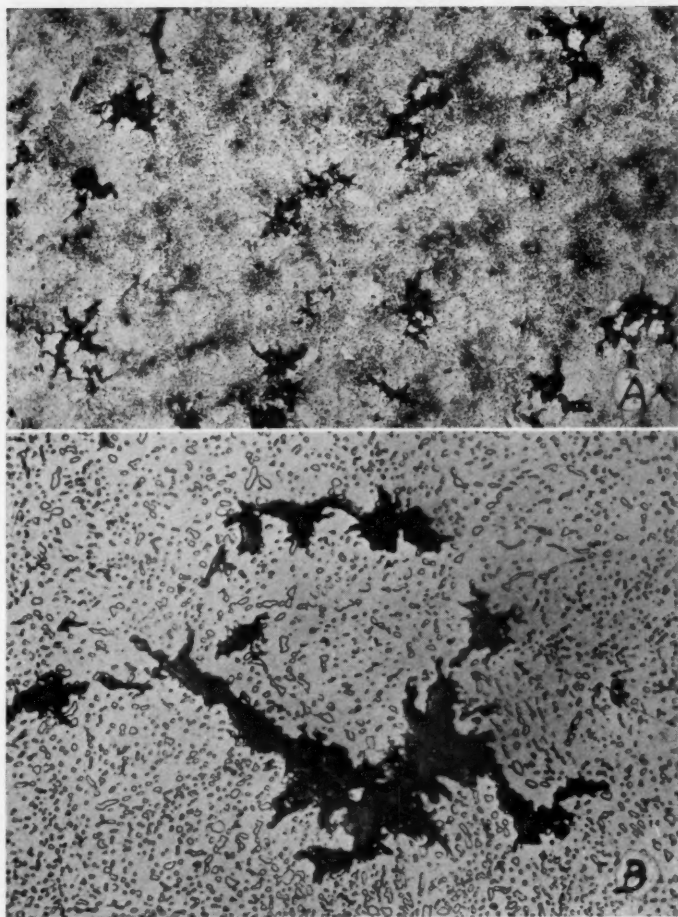


FIG. 3—TYPICAL SECTION OF SPECIMENS III B, QUENCHED FROM 1525° F. AND DRAWN 4 HOURS AT 1325° F.—(A) X100, ETCHED, (B) X1000, ETCHED.

heat treatment B, the 4-hour draw. The photomicrograph Fig. 4 shows normal, fully-annealed malleable iron.

44. The structure of the molybdenum irons is so nearly the same that no useful purpose would be served to photograph them.

45. Heat treated malleable irons are frequently produced by slowly cooling through the critical range without resorting to the use of a quench and temperature procedure. Such a treatment will usually result in a pearlitic matrix. The physical properties are not so readily controlled due to the fact that the temper carbon particles are usually surrounded by a bull's eye of ferrite. This is shown in the photomicrographs (Fig. 5A and B) at 100 and 1000 diameters, respectively. Irons of this general nature are frequently used as brake drums. The best wear properties are, however, obtained when the bull's eye structure has been reduced to a minimum. Manganese seems to be quite beneficial in reducing the quantity of ferrite obtained by cooling slowly through the critical to 1200° F. and air quenching.

46. As can be seen in the photomicrograph Fig. 6A, 0.15 per cent molybdenum does not slow down the formation of ferrite although it will increase the time necessary to break down the primary cementite. Chromium in concentrations of 0.15 per cent and 0.3 per cent seems to favor spheroidization of the cementite in the above heat treatment. This can be seen in the photomicro-

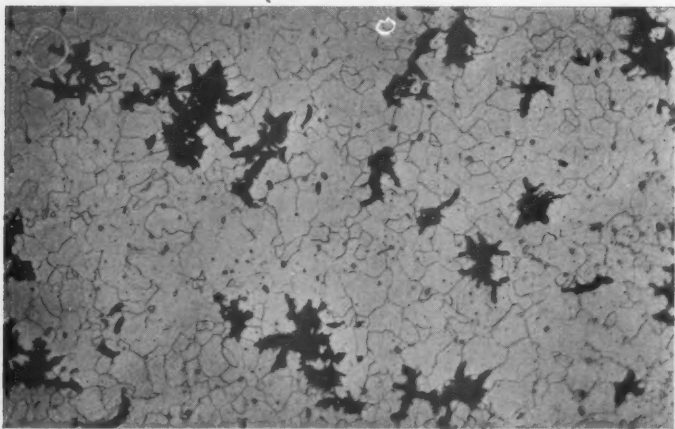


FIG. 4—TYPICAL SECTIONS OF IRON III C, FULLY ANNEALED—X100. ETCHED.

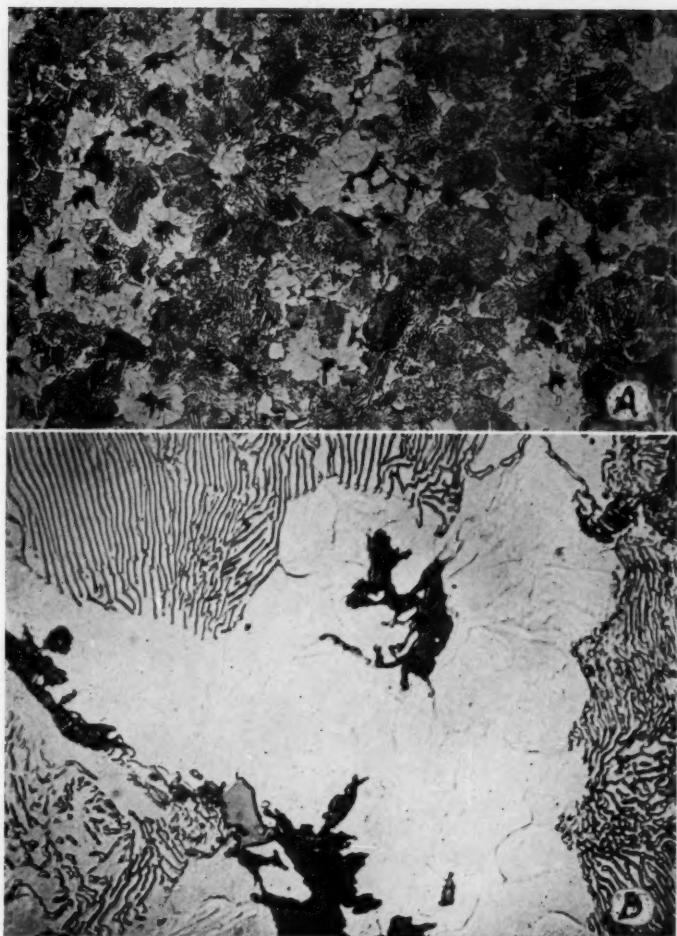


FIG. 5—SECTION OF PEARLITIC MALLEABLE—(A) X100, ETCHED, (B) X1000, ETCHED.

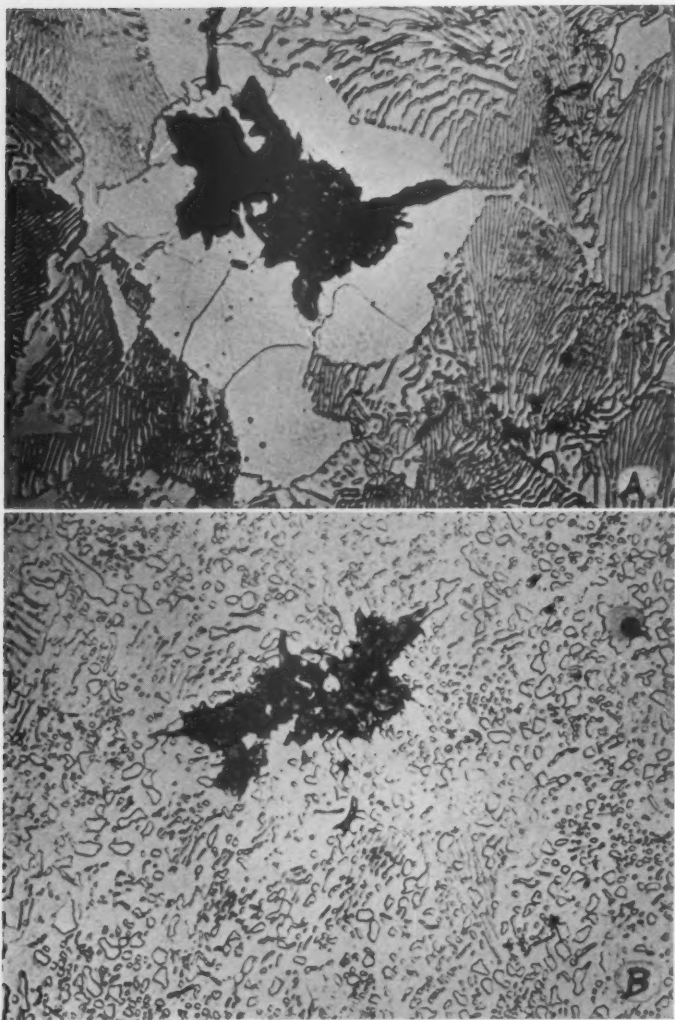


FIG. 6—(A) IRON CONTAINING 0.15 PER CENT MO.—X1000; (B) IRON CONTAINING 0.15 PER CENT CR.—X1000, ETCHED.

graphs Figs. 6B and 7A. The time necessary to break down the primary cementite was increased slightly. One-tenth per cent of vanadium added to normal Z metal increased the difficulty of breaking down the primary cementite. The photomicrograph Fig. 7B shows a specimen which had been heated to 1700° F., cooled in the furnace to 1500° F. and quenched. It was then tempered at 1300° F. The presence of free carbides and of pearlite or spheroidized carbide was visible. Chromium as well as vanadium seems to favor the formation of a uniform matrix with respect to bull's eye structure. This latter structure seems to have rather favorable wear resistance.

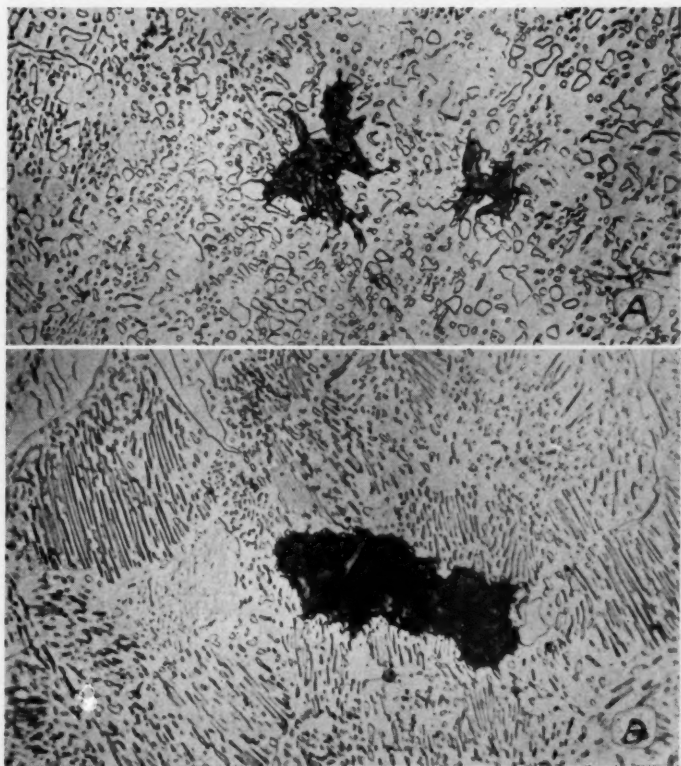


FIG. 7—(A) IRON CONTAINING 0.30 PER CENT CR.—X1000, ETCHED; (B) Z METAL CONTAINING 0.15 PER CENT VANADIUM—X1000, ETCHED.

Table 14
PHYSICAL PROPERTIES OF MALLEABLE IRONS

Iron	Modulus of Elasticity lb. per sq. in.	Proportional Limit	<i>Tensile Properties</i>			<i>Compression Properties</i>		
			Yield Point lb. per sq. in.	Tensile Strength lb. per sq. in.	Elongation per cent	Brinell Hardness	Yield Point lb. per sq. in.	Stress at 2% Deformation lb. per sq. in.
III A	25,475,000	39,040	60,300	76,150	6.5	231	59,832	70,600
III B	25,408,333	30,152	50,032	64,542	8.4	183	57,770	66,870
III C	25,072,667	18,050	37,325	52,033	14.6	133	35,488	52,900
McA	.....	.....	70,587	77,783	3.5	245	70,050	110,875
McB	.....	.....	64,982	73,982	7.9	223	77,175	104,925
McC	.....	.....	37,225	54,485	15.1	130	43,737	81,037

Table 15

CHARPY IMPACT PROPERTIES AT ROOM AND ELEVATED TEMPERATURES

Iron	Impact—Foot Pounds			400° F.	800° F.
	80° F.	400° F.	800° F.	Cooled to 80° F.	Cooled to 80° F.
III A	7.8	8.2	6.3	6.9	7.8
III B	8.9	9.4	7.3	8.8	9.5
III C	11.3	10.5	8.3	11.8	12.5
MoA	4.0	4.3	3.3	4.0	3.9
MoB	5.0	6.2	5.0	6.5	6.0
MoC	10.0	9.7	7.0	11.8	11.5

Table 16

TORSION PROPERTIES

Iron	Torsion or Shearing Modulus	Proportional Limit	Yield Point	Rupture	Angle of Twist
	lb. per sq. in.	lb. per sq. in.	lb. per sq. in.	lb. per sq. in.	at Rupture degrees in 12 in. gage length
III A	7,084,000	28,560	36,480	59,320	228
III B	7,532,000	26,780	38,520	60,500	262
III C	7,172,000	11,168	15,690	37,080	453
MoA	9,562,500	37,425	44,900	69,950	180
MoB	9,490,000	30,750	39,950	63,167	184
MoC	8,120,000	15,640	19,583	52,533	401

Table 17

TRANSVERSE PROPERTIES

Iron	Modulus of Rigidity	Proportional Limit	Yield Point	Modulus of Rupture	Maximum Deflection	Depth,	Width,
	lb. per sq. in.	lb. per sq. in.	lb. per sq. in.	lb. per sq. in.	in.	in.	in.
III A	23,060,000	62,066	84,933	131,200	0.998	1.356	0.496
III B	22,000,000	49,233	73,367	118,167	1.025	1.433	0.494
III C	17,530,000	28,750	46,283	78,333	2.24	1.421	0.520
MoA	24,202,000	81,180	.....	139,440	0.430	1.364	0.500
MoB	23,638,333	66,183	.....	135,520	0.561	1.404	0.501
MoC	21,660,000	37,320	47,820	91,000	1.56	1.428	0.514

Table 18

FATIGUE PROPERTIES OF MALLEABLE IRON

Iron	Endurance Limit
	lb. per sq. in.
III A	30,500
III B	26,800
III C	22,100
MoA	31,350
MoB	28,100
MoC	23,000

SUMMARY AND CONCLUSIONS

47. The results of the work done on the study may briefly be summarized as follows:

(1) The purchase on chemical specification of quick anneal malleable iron for the purpose of heat treatment and full anneal proved to be fairly successful. The physical properties obtained were quite uniform although there were some differences in the annealing rates. These were not great when consideration is taken of the different methods of manufacture and different types of charge used.

(2) In the heat treated condition, malleable iron exhibits strengths approaching those of steel. The presence of temper carbon, however, renders the material less ductile. The properties should find a wide field of industrial use.

(3) The addition of 0.5 per cent molybdenum retards the rate of graphitization a little but results in a stronger material. This is especially noticeable in compression and torsion.

(4) The results of physical tests are condensed in Tables 14, 15, 16, 17, 18 and 19.

ACKNOWLEDGMENTS

48. The writers wish to acknowledge gratefully the assistance and support of Mr. H. B. Tyree of the Detroit Edison Company and Mr. A. J. Herzig, of the Climax Molybdenum Company, under whose sponsorship the study was carried out.

49. The writers are indebted to Messrs. A. L. Boegehold, General Motors Corporation, Detroit, Michigan; E. E. Griest, Chicago

Table 19

HIGH TEMPERATURE TENSILE PROPERTIES

Iron	Tensile Strength, lb. per sq. in.			Proportional Limit, lb. per sq. in.			Elongation Per Cent		
	80° F.	400° F.	800° F.	80° F.	400° F.	800° F.	80° F.	400° F.	800° F.
III A	76,150	74,725	65,788	39,040	33,750	20,000	6.5	4.1	6.7
III B	64,442	62,088	59,075	30,152	24,150	13,750	8.4	6.3	8.2
III C	52,058	48,188	44,580	18,000	13,750	11,670	14.6	8.2	10.0
MoA	77,783	77,788	76,612	—	40,000	29,170	3.5	1.4	2.8
MoB	73,962	73,838	73,837	—	38,340	22,500	7.9	2.4	3.6
MoC	54,485	52,862	45,680	—	17,500	13,750	15.1	3.0	5.5

Railway Equipment Company, Chicago, Illinois; R. E. Kennedy, American Foundrymen's Association, Chicago, Illinois; W. H. Doerfner, Saginaw Malleable Iron Company, Saginaw, Michigan; C. Joseph, Saginaw Malleable Iron Company, Saginaw, Michigan; Enrique Touceda, Touceda Laboratories, Albany, New York; who gave valuable advise and encouragement in outlining the scope and procedures of the present study.

DISCUSSION

J. W. HAMILTON¹: The authors, once again, are to be congratulated on their presentation of this very excellent work on malleable cast iron. We would like to point out at this time that their endurance limit values for the fully annealed iron seem to us low. At the Toronto meeting of the AMERICAN FOUNDRYMEN'S ASSOCIATION two years ago, Dr. E. G. Mahin and myself presented a paper on the subject of endurance limit of malleable iron² and we were able to show that the ratio of tensile strength to endurance limit was 0.54. Since that time, we have had occasion to check some other workers in the field and a value of from 28,000 to 30,000 lb. per sq. in. has been found to be accepted most generally.

R. E. SCHNEIDEWIND: There are two things that may account for our somewhat low endurance limits: First is that this is a quick-anneal malleable with a high amount of silicon which may have some effect, and the second is that some of these specimens were heat treated commercially and evidently the furnace used was not particularly uniform and the endurance specimens were on the cold side of the furnace. We had to re-heat-treat them after machining so they were machined down slightly under size, which may have left some surface defects. Although the furnace atmosphere was carefully controlled there was a slight amount of scale which had to be taken off with a single cut and polished with emory.

It is quite possible that the surface roughness or a small surface defect would have lowered our endurance values somewhat.

CHAIRMAN P. C. DEBRUYNE³: We owe Dr. Schneidewind and Dr. White a vote of thanks for the wonderful work they have done in presenting this paper. I really feel that if they keep this up, we will be making malleable iron without annealing.

C. F. JOSEPH⁴: We have for quite some time been making various castings out of this particular metal such as pistons and rocker arms and camshafts, and I think there is a chance for everybody to get into the field and make many kinds of castings out of this particular metal.

¹ Research Metallurgist, Vanadium Corp. of America.

² *Endurance Limit of Black Heart Malleable Iron*, Mahin, E. G., and Hamilton, J. W., TRANS. A.F.A., vol. 43 (1935).

³ Moline Malleable Iron Co., St. Charles, Ill.

⁴ Metallurgist, Saginaw Malleable Iron Div. General Motors Corp., Saginaw, Mich.

You can obtain physical properties all the way from 85,000 to 115,000 lb. per sq. in. with elongation of from 1.5 to 5.0 per cent. This allows you to make a wide variety of castings, such as pistons, cam shafts, crank shafts and a lot of other parts.

The paper which Dr. Schneidewind gave us was very interesting and I am positive that there is a big future for castings along this line.

Determination of the Basin Capacity of a Cupola

By J. A. BOWERS*, BIRMINGHAM, ALA.

1. The question of the basin capacity of a cupola quite often arises in all foundries where the cupola is tapped. This is a particularly vital question when a new cupola is being installed and the tuyeres must be placed sufficiently high that the basin will hold enough iron for particular jobs. For this reason, the study discussed in this paper was made to determine the percentage of the space in a cupola basin available for molten iron.

THE INVESTIGATION

Charges

2. The tests were made on a hand charged cupola using a good grade of standard size, 3-in. and up, foundry coke. The actual measured coke size of an average charge used in these tests was as follows:

	Inches
Maximum	$6\frac{1}{2} \times 5 \times 4$
Minimum	$1 \times \frac{1}{2} \times \frac{1}{2}$
Average	$3\frac{1}{2} \times 2\frac{1}{2} \times 2$

3. The metal was made up into 3000 lb. charges. The weight of the coke splits was 250 lb., and 80 lb. of dolomite were used on each charge of coke.

Measurements and Calculations

4. Measurements were made of the cupola basin before each heat. Calculations were made to determine the volume, in cubic inches, using the distance from the top of the tap hole to the bottom of the slag notch as the effective height.

5. The determinations were made in each case after 10,000 lb. of iron had been removed from the cupola. This was done to be sure that the basin had assumed what might be termed its

* Melting Superintendent, American Cast Iron Pipe Co.

NOTE: This paper was presented before a Shop Operation Course Session of the 41st Annual Convention, Milwaukee, Wis., May 3, 1937.

average condition. Another reason for this delay in beginning the tests was that it is reasonable to assume that when iron appears at the slag notch for the first time, there would be more available space for molten iron in the basin than at any other time during the heat because the coke is not as contaminated with slag, etc.

6. The method used was as follows: The elapsed time from the appearance of slag at the tap hole to the appearance of iron at the slag notch and also the time necessary to drain the basin until slag appeared again at the tap hole was checked with a stop watch. The amount of iron collected was carefully measured and by dividing this by the above time, the melting rate of the cupola was determined. By checking the time necessary to refill the basin and using the above melting rate, the basin capacity was calculated.

Results Obtained

7. The data collected are given in Table 1.

Table 1
BASIN CAPACITY DETERMINATIONS

Test No. 1

Average diameter of the cupola basin, in.....	56
Effective height for the molten iron, in.....	10.75
Calculated basin capacity, cu. in.....	26,450

	Determination		
	1st	2nd	3rd
Filling and tapping time, min. and sec.....	7 - 20	8 - 35	8 - 55
Time of refill, min. and sec.....	6 - 25	5 - 25	5 - 40
Amount of iron tapped, cu. in.....	12,080	13,400	16,720
Melting rate per minute, cu. in.....	1,645	1,560	1,870
Actual basin capacity, cu. in.....	10,560	8,460	10,610
Average basin capacity, Actual, cu. in.....	9,880	.....	.....

Test No. 2

Average diameter of the cupola basin, in.....	57.5
Effective height for iron, in.....	12.0
Calculated basin capacity, cu. in.....	31,060

	Determination			
	1st	2nd	3rd	4th
Filling and tapping time, min. and sec...13-30	12- 0	12-25	12-30	
Time to refill, min. and sec..... 9-15	9-50	10- 0	8-30	
Amount of iron tapped, cu. in.....14,330	14,330	15,175	14,800	
Melting rate per minute, cu. in..... 1,060	1,195	1,220	1,185	
Actual basin capacity, cu. in..... 9,815	11,750	12,220	10,080	
Average basin capacity, Actual, cu. in.....	10,950	.....	.....

Possible Causes of Variation

8. An explanation of the cause for the 22 per cent variation in basin capacity in both sets of tests, that seems plausible to the writer, is that the basin capacity would be variable to a certain extent. This could be caused by a change in the viscosity of the slag. A highly viscous slag would cling to the coke with more tenacity than a more fluid slag and, therefore, there would be less available space for the molten iron.

9. It seems highly probable, too, that the coke in the immediate vicinity of the tap-hole could be dissolved by the iron flowing from the basin. This would leave a hollow space just over and around the tap-hole. The iron flowing from a tap-hole under this condition could in effect form a whirl-pool and allow slag to be drawn from the surface of the iron. This would deceive the observer into thinking that the slag level had reached the top of the tap hole and thus his observed data would give a lower basin capacity.

CONCLUSIONS

10. Using the average basin capacity from these tests, it was found that only 37 per cent of the calculated basin capacity was available for molten iron in Test 1. Test 2 gave 35 per cent as its capacity. This is a reasonably close check and, therefore, it seems perfectly logical to say that from 35 to 40 per cent of the calculated basin capacity of a cupola is available for molten iron.

A CHECK TEST

11. To check the above results, a set of additional tests were made using new coke from the same car as that used above, together with coke recovered from the cupola drop. The bottom coke was collected with a standard coke fork with $1\frac{3}{8}$ in. between prongs.

12. The coke was charged into a drum 39 in. in diameter. The drum was equipped with an overflow nozzle and when full had a capacity of approximately 30,000 cu. in. The results of these tests were as given in Table 2.

13. The size of the new coke used would closely approach that as charged into the cupola. A representative sample of the bottom coke was measured and was as follows:

	Inches
Maximum	$7\frac{1}{2} \times 4 \times 4$
Minimum	$1 \times \frac{1}{2} \times \frac{1}{2}$
Average	$3\frac{1}{2} \times 2 \times 1\frac{1}{2}$

14. The close results obtained on these tests of new coke and recovered bottom coke indicate that there was very little contamination of the coke in the cupola basin. The bottom coke used in this test, as most bottom coke is, had been subjected to the draining of the cupola which surely would have brought all the slag on the iron into intimate contact with it just before the drop. It seems logical to conclude from this that most of the 20 per cent reduction in available space in the cupola basin was due to the compactness of the coke caused by the great weight in the cupola stacks.

Table 2

DETERMINATIONS FOR VARYING BASIN CAPACITY

Test No. 1

11 in. of water in drum, cu. in.....	13,060
11 in. of coke (new) displaced, cu. in.....	5,583
11 in. of coke (bottom) displaced, cu. in.....	6,030
Available space for water with new coke, per cent.....	57.3
Available space for water with bottom coke, per cent.....	53.9

Test No. 2

24 in. of water in drum, cu. in.....	28,610
24 in. of coke (new) displaced, cu. in.....	12,935
24 in. of coke (bottom) displaced, cu. in.....	13,330
Available space for water with new coke, per cent.....	54.8
Available space for water with bottom coke, per cent.....	53.3

Progress Report of Committee on Fluidity Tests¹

To Members, Gray Iron Division, American Foundrymen's Association:

1. The term fluidity to the physicist means the reciprocal of viscosity, or the lack of internal friction in a flowing substance. Fluidity, when applied to molten metals in a foundry, has the broader meaning of ability of a molten metal to flow and completely fill a mold. This definition of fluidity takes into account not only the internal friction of the metal, but also its surface tension as well as the nature of the mold.

2. Since this is one of the important properties of the metal from a foundry viewpoint, many attempts have been made to devise a fluidity test. The best results have been obtained with the spiral fluidity test² as perfected by Saeger and Krynitsky of the National Bureau of Standards, Washington, D. C.

3. The fluidity of a molten metal is governed by the following formula given by Portevin and Bastien:

$$\Delta = \alpha \frac{c d (0 - F)}{F - \theta} \quad \beta \frac{L d}{F - \theta}$$

where Δ = castability or fluidity

α } depend on the nature of the mold and the viscosity
 β } of the metal

c = specific heat of the liquid metal

d = density of the metal

0 = casting temperature

F = solidification temperature of the metal

θ = temperature of the mold

L = latent heat of solidification of the metal

4. It would seem logical to consider that the nature of the film on the molten metal would influence its surface tension and be a factor in α and β .

5. From the above considerations we may draw the following conclusions in regard to the factors affecting the fluidity of a molten metal:

(a) Fluidity does not depend on casting temperature

¹ NOTE: Progress Report of Gray Iron Division Committee presented before Division Session at Milwaukee Convention, May 4, 1937.

² Saeger, Jr., C. M. and Krynitsky, A. I. "Practical Method for Studying the Running Quality of a Metal Cast in Foundry Molds," TRANS. A.F.A. Vol 39 (1931), pp. 513-532.

alone, but on the difference between the casting temperature and the solidification temperature of the metal, (0—F). Therefore, fluidity measurements made on metals of varying composition must take into account the difference in solidification temperature as well as those in casting temperature.

(b) For any given metal, variation in casting temperature affects the viscosity and surface tension of the metal, as well as the length of time it remains molten and the mold temperature. This makes the casting temperature one of the most potent variables in fluidity measurements.

(c) A change of composition in the metal will affect its viscosity, solidification temperature, and possibly the surface tension.

(d) Crystals formed in the interval between the formation of the first solid and the total solidification of the metal affect the viscosity of the metal and in extreme cases, where kish is being formed, may even mechanically choke the gate.

(e) According to Portevin and Bastien, fluidity also depends on the form taken by the crystals. Crystals with convex faces (definite compounds) formed in the liquid do not hinder flow as greatly as do dendritic crystals (solid solution). Eutectic mixtures are most fluid in an alloy series.

(f) The mold temperature and levelness, the nature of the sand and ramming, all seem to be of some importance in determining the fluidity of the metal, but the use of the standard mold, as reported by Saeger and Krynitsky, gives reproduceable results. Naturally, this standard mold must be prepared with ordinary foundry care and attention.

6. In the application of the fluidity test as a routine shop control test, we heard several objections:

- (1) Cost of molds;
- (2) Sensitivity to casting temperature variations;
- (3) Individual methods already in use.

On the other hand, we have been told that it was used for the following reasons:

- (1) to determine whether misruns were due to metal or to molding;
- (2) to find the proper pouring temperature for any composition of metal, where the required fluidity was known;
- (3) to check the mixing and melting operation for uniformity.

7. Taking all of this into consideration, it would seem that

the spiral fluidity test is a tool which might be employed to advantage both in research and control work.

8. A bibliography on fluidity testing is appended to this report.

Respectfully submitted,

Gray Iron Division Committee on Fluidity Tests

W. H. SPENCER, *Chairman*

M. KUNIANSKY

J. T. MacKENZIE

C. M. SAEGER, Jr.

C. F. JOSEPH

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Report on Steel Castings Specifications

*To Members of the Steel Division,
American Foundrymen's Association:*

This is a verbal report as your Association representative on the American Society of Testing Materials, Committee A-1.

Last year you were told that Subcommittee 8 of A.S.T.M. had submitted to Committee A-1, revised specifications for steel castings with the suggested designation of A27-36T, for adoption as a tentative standard. Those specifications were accepted by Committee A-1, and are now tentative specifications of the American Society for Testing Materials for miscellaneous usages.

The other matter of interest to this division is the appearance of a growing number of specifications which provide for non-destructive testing. The steel foundries have recognized this situation through the Steel Founders' Society of America. The board of directors of the Steel Founders' Society has provided a paid technical secretary, whose duties it will be to make a critical examination of specifications that are submitted to the steel casting industry with the idea of making recommendations to the industry after committee discussion. Members of the American Foundrymen's Association are on that committee.

It is not intended that the technical secretary of the Steel Founders' Society shall tell people how to meet specifications—it is only intended that he examine specifications in a general way with reference to their practical application.

The non-destructive testing situation apparently is in a formative stage. Reports undoubtedly will be made from time to time as the committee work progresses, telling the industry from the standpoint of the practical man what the use has been and what the limitations are of the interpretation of these various methods of non-destructive testing.

The American Society for Testing Materials will meet again, of course, in June. Opportunity will be given to make suggestions as to possible changes in the Tentative Specification A27-36T. I

NOTE: This report was presented before the Steel Division Session of the 41st Annual A.F.A. Convention, Milwaukee, Wis., May 4, 1937.

should like at this time to have those suggestions, if there are any, so that I may present them to Subcommittee 8 when it meets in June of this year.

Respectfully submitted,

E. W. CAMPION,*

*A.F.A. Representative on
A.S.T.M. Committee A-1.*

* President, The Bonney-Floyd Co., Columbus, Ohio.

Selection of Cycle and Furnace for Annealing Malleable Iron

By A. F. LANDA,* MOSCOW, U. S. S. R.

Abstract

The author has made a study of annealing cycles and equipment used for the annealing of malleable iron. He illustrates the various cycles schematically and divides each scheme into periods. After explaining the advantages and disadvantages of the various cycles, he states the points that must be taken into consideration when selecting a cycle for use. He has also investigated the adaptability of the various heating furnaces to the cycles under discussion. The author reaches the conclusion that there is no "accelerated" annealing of malleable iron but rather an optimum annealing cycle, dependent upon the iron to be annealed and the furnace equipment available. He also states that cycles can be reduced by lowering the "non-productive time", during which annealing is not taking place. He is of the opinion that furnaces should be designed to make them suitable to the desired cycle and to the castings to be annealed. The author describes a type of tunnel kiln devised by Russian engineers and states in his conclusions that the modifications devised by them should be introduced into new furnaces for the purpose of lowering the required annealing time.

1. Any cycle for annealing malleable iron to obtain a ferrite-graphite structure is composed of (a) the time necessary for the graphitization, and (b) the time necessary for the heating and cooling of castings. Special attention must be paid to methods of so-called "accelerated annealing." These methods often are considered as special cycles, easily accomplished only in electric furnaces.

2. All annealing cycles, including the so-called "accelerated annealing" may, in the author's opinion, be easily reduced to a

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small number (5) of schemes. Each scheme is indicated by a corresponding sketch in Fig. 1. These may be divided into five periods:

First Period (Line AB—Schemes A, B, C and D): Heating of castings to high temperatures above the line (Line P'

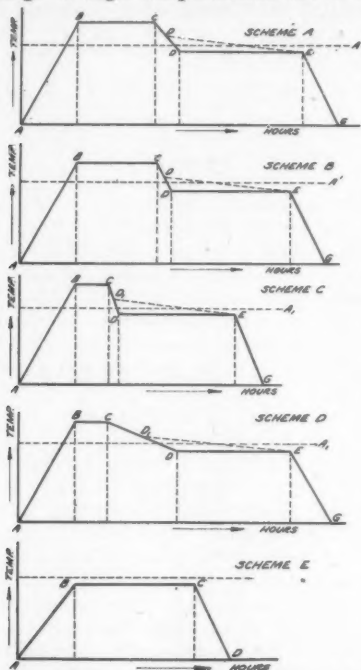


FIG. 1—SCHEMES OF CYCLES FOR ANNEALING OF MALLEABLE IRON. SCHEMES A, B, C, D, E. ARE REPRESENTED BY SKETCHES A, B, C, D, E.

S' K', Fig. 2). (Line AB—Sketch E): Heating of castings a little below point A_1 .

Second Period (Line BC, Schemes A and B): Maintenance of castings at temperatures above A_1 (the line P' S' K', Fig. 2) to complete destruction of massive cementite, to reach stable equilibrium, and to form a structure comprising temper carbon plus solid solution. This period is called the *first stage of graphitization*. (Line BC, Schemes C and D): Maintenance of castings for a short period at temperatures above A_1 . The first stage of graphitization is not completed, and only centers of graphitization are formed.

Third Period (Line CD, Scheme A): Cooling castings at a rate corresponding to the graphitization rate of stable solid solution in the direction of the line $E'S'$ (Fig. 2), the so-called intermediate stage of graphitization. (Line CD, Schemes B and C): Rapid cooling from temperatures of the first stage of graphitization to the temperatures of the second stage of graphitization, at a rate *exceeding the rate of* graphitization, along A_{gr} , the line $E'S'$ (Fig. 2). (Line CD, Scheme D): Slow cooling from the temperatures of the first

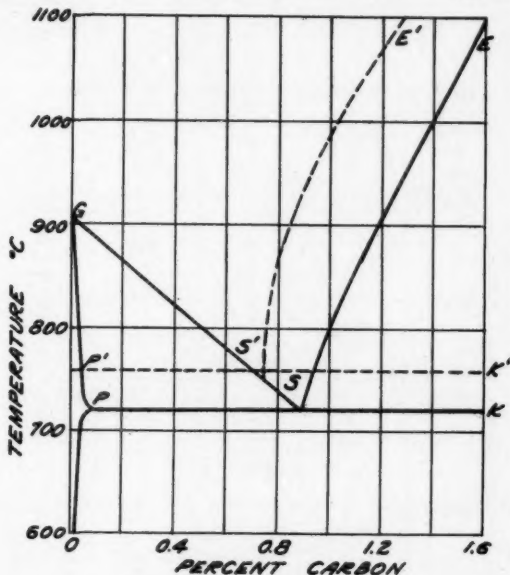


FIG. 2—IRON-CARBON DIAGRAM.

stage of graphitization to the temperatures of the second stage of graphitization at a *slower rate than the rate of* graphitization along A_{gr} (line $E'S'$, Fig. 2). The destruction of the remaining massive cementite of the incomplete first stage of graphitization should take place at this stage.

Fourth Period (Line DE, Schemes A, B, C, D and line BC of scheme E): (a) Maintenance at temperature slightly below the pearlite point up to the complete formation of temper carbon and ferrite, or (b) line $D'E$ for schemes A, B, C and D—very slow cooling with the purpose of getting

through the critical stage at a rate corresponding to the direct transformation of solid solution into ferrite and tempered carbon. This period is called the *second stage of graphitization*.¹ In both cases the graphitization of massive cementite remaining from the first stage of graphitization should be completed during the second stage of graphitization.

Fifth Period (Line *EG*, Schemes A, B, C and D and line *CD*, Scheme E): Cooling of castings to normal temperature.

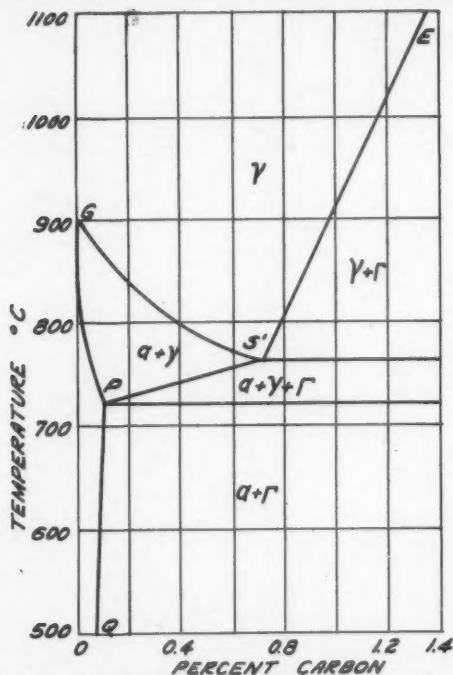


FIG. 3—IRON-CARBON DIAGRAM IN PRESENCE OF SILICON.

3. Theoretically, the second stage of graphitization may be accomplished either (a) by slowly traversing the critical point, with the formation of ferrite and temper carbon directly from solution (dotted lines on Fig. 1), or (b) by short maintenance at sub-critical temperature for the purpose of graphitizing pearlite, which is formed by a more rapid cooling rate.

¹ The second stage of graphitization may be accomplished as well by fluctuation of temperature around the pearlite interval, but this method is difficult under present working conditions.

4. We consider the first method more rational and rapid. The better the control of temperature distribution in the furnace and the more uniform the composition of metal, the more suitable is the first method. The second stage of graphitization may be accomplished in a very narrow interval of temperatures, and, consequently, in a time as short as required.

SLOW COOLING MOST PRACTICAL

5. Practically, it would also appear more reasonable to carry on slow cooling through the critical point, as the analyses of castings are generally variable, and, therefore, the critical points are not constant.

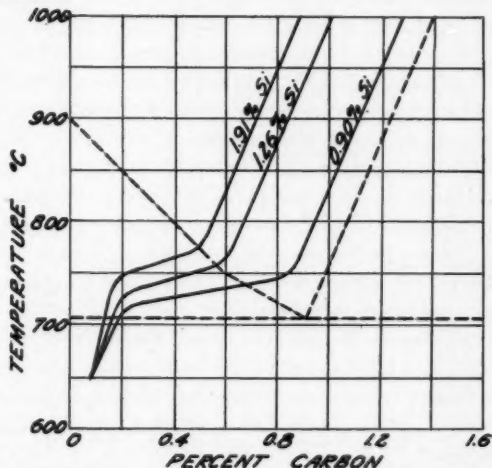


FIG. 4—DIAGRAM OF EQUILIBRIUM OF COOLED IRON-CARBON ALLOYS WITH VARYING PERCENTAGES OF SILICON (WHITE AND SCHNEIDEWIND).

6. If the graphitization of the second stage takes place somewhat below the eutectoid point *S* (Fig. 2), the temperature must be selected in accordance with the castings having the lowest critical point. This means that for the other castings the temperature of graphitization would be too low, and graphitization would be needlessly prolonged. It is also more difficult to create and maintain an absolutely equal temperature in all parts of an ordinary furnace.

7. Our experience shows that the best rate of graphitization in the second stage is obtained with slow passage through the critical points, and not with maintenance at one temperature.

CONSIDERATIONS IN SHORTENING ANNEAL

8. Analyzing these procedures from the point of view of shortening the period of annealing, the following may be stated:

9. Scheme *E* might be useful for types of iron with very high critical points, and easy graphitization; for example, iron with high silicon contents (and low carbon contents) may be graphitized, especially in the case of rapid cooling of liquid metal (in metal moulds, etc.), at temperatures of 800-850° C. (1470-1560° F.), *i. e.*, below critical point.* Both the first and the second stage of graphitization would be completed. This scheme would be too long for iron of usual composition.

10. Scheme *C* might be preferable when the castings contain elements which chiefly hinder the second stage of graphitization, but cannot be considered acceptable for iron of usual composition. Thus, only schemes *A*, *B* and *D* remain and should be considered from the point of view of their adaptability for the manufacture of malleable iron of usual composition.

11. The time required for the intermediate stage of graphitization, according to the latest investigations of Mertz and Schuster, is very short, as it would appear that the equilibrium of the system is not destroyed even with a cooling rate of 100° C. (180° F.) per hour. Therefore, scheme *B* has no advantages in comparison with scheme *A* (see Fig. 1).

12. The question of whether *A* or *D* should be applied, would depend upon the construction of the ovens and the conditions of annealing. Tunnel kilns and annealing ovens of periodic type (chamber ovens) are suitable for schemes *A* and *D* when appropriately designed.

EFFECT OF HEATING SPEED ON ANNEALING CYCLE

13. With any tunnel kiln or chamber oven and any scheme of annealing, we should try to obtain heating at maximum speed; this also applies to final cooling, and may be reached very often. It is more difficult to construct an oven in which intermediate cooling would take place with sufficient speed at a rate corresponding to the rate of intermediate graphitization. Natural cooling with castings together in the oven does not often exceed 7-10° C. (12.6-18° F.) per hour, whereas the rate of intermediate graphitization permits cooling at 100° C. (180° F.) per hour.

14. It is useless to completely decompose massive cementite

* EDITOR'S NOTE: Under American conditions, alloys so high in critical point would be at least unusual.

in the first stage of graphitization in ovens with very slow intermediate cooling. It would be more rational to effect annealing in accordance with scheme *D*.

15. When it is not possible to heat the furnace to high temperatures with sufficient speed, the graphitization may be practically completed long before the desired maximum temperature has been reached. It is then useless to reach very high temperatures.

16. Accordingly we would consider that each oven, depending upon its rate of heating, rate of cooling, and the castings to be annealed, has its own maximum temperature. There is no necessity of heating the castings² above this temperature, and in the cycles shown diagrammatically in Fig. 1, the length of the line *BC* of schemes *A*, *B*, *C* and *D* may even be reduced to zero. This maximum temperature would be lower in the cases when intermediate cooling between the first and the second stage of graphitization can not proceed very rapidly owing to the characteristics of the given oven. The longer the heating and intermediate cooling, the lower should be the maximum temperature, at which the annealing is to be effected.

17. When the cooling of the castings proceeds slowly in the oven to a temperature near atmospheric, the duration of the second stage of graphitization may be reduced by leaving a certain part of pearlite, which would continue to decompose at temperatures considerably below 700° C. (1292° F.).

CONSIDERATIONS IN SELECTING AN ANNEALING CYCLE

18. When determining the annealing cycle, the following should be considered: (1) The rate of heating and cooling of castings in the given oven; (2) To choose on the basis of point 1, the maximum temperature and the time for the first and second stages of graphitization.

19. The ovens may be divided into the following groups:

(a) Ovens in which heating and intermediate and final cooling are easily accomplished with great speed.

(b) Ovens in which heating and final cooling are accomplished with great speed, but intermediate cooling is very slow.

(c) Ovens in which heating is accomplished with great speed, but intermediate and final cooling is very slow.

²Independent of the ovens used, it is recommended not to heat castings above 1050° C. (1920° F.) owing to considerable warping and possible fusion.

(d) Ovens in which heating is slow and intermediate and final cooling is rapid.

(e) Ovens in which heating and final cooling are slow and intermediate cooling rapid.

(f) Ovens in which heating, and intermediate and final cooling are slow.

20. The selection of the annealing method should depend upon the characteristics of the ovens, while the length of time at definite temperatures should be selected with a view to the composition of iron and the annealing method.

21. It is easy to see that, whereas the duration of the first and second stage of graphitization may be varied, the time required for the heating and final cooling of castings is constant, and depends upon the characteristics of the ovens. The time allowed for the first and second stage of graphitization should be based not only upon the character of the castings, but also upon the time required for the heating and intermediate cooling.

22. We would recommend schemes *A* or *B* (Fig. 1), as most appropriate for the ovens of groups (a) (d) (e), since intermediate cooling in these ovens is rapid. In practice the length of the line *AB* of schemes *A* or *B* may be reduced to zero for ovens of groups (d) and (e). Annealing in ovens of groups (b), (c) and (f) should be accomplished in accordance with scheme *D*, since intermediate cooling is very slow.

23. The fact that annealing in ordinary chamber ovens, tunnel kilns, and in the 25-ton electric furnaces is very slow (up to 100-120 hrs.) in comparison with certain 6-ton electric furnaces, the duration of annealing in the latter being 25-30 hours., led us to the supposition that, in practice, we have to deal not only with the deficiencies in the characteristics of the given ovens, but also with an incorrect selection of annealing cycles for these ovens.

INVESTIGATES ANNEALING EQUIPMENT

24. With a view to shortening annealing time, we have investigated the annealing cycles in electric furnaces, ordinary chamber ovens and tunnel kilns.

Electric Chamber Furnaces

25. The short 24 to 30 hr. cycle (see Fig. 5) of the General Electric Co. is obtained in electric furnaces, which may be referred to group (a) of our classification, since (1) the atmosphere in the furnace permits annealing without packing material, and

(2) the absence of packing permits heating to high temperatures about 1000°C . (1830°F .), where the decomposition of cementite proceeds very rapidly compared with the usual temperature of $870\text{--}900^{\circ}\text{C}$. ($1600\text{--}1650^{\circ}\text{F}$.) in tunnel kilns and chamber ovens. The absence of packing makes possible the cooling of the castings at any desired stage of the cycle.

26. According to Kikuta³ castings cooled upon completion of the second stage of graphitization at a rate not less than 100°C . (180°F .) per hr. are not subject to the well known "white fracture."

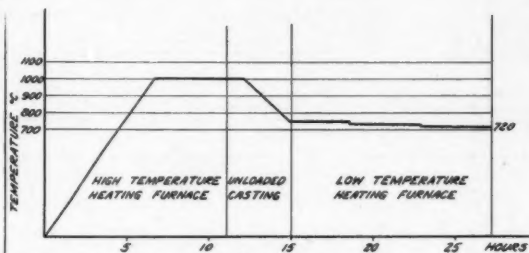


FIG. 5—DIAGRAM OF ANNEALING MALLEABLE IRON IN ELECTRIC FURNACES OF GENERAL ELECTRIC COMPANY.

27. When the annealing of the castings is effected in sand as in ordinary chamber ovens and tunnel kilns, it is not possible to obtain such rapid cooling of the castings, therefore, they must be cooled slowly to the temperature below 250°C . (480°F .), and only after this, it is possible to open the annealing pots.

28. The 72-hr. cycle in 25-ton electric furnaces of the Industrial Furnace Co.⁴ is carried out in accordance with scheme B (See Fig. 6).

29. These furnaces may be referred to group (d) of our classification. The temperatures of annealing and the entire cycle, in our opinion, are not the best possible. (The maximum temperature (1700°F .) is too low, etc.)

30. Heating takes place slowly. The castings are raised to 900°C . (1650°F .) in 15 hours. Cooling the castings from that temperature to the temperature of 728°C . (1340°F .), and the levelling of the furnace to that temperature requires 7 hrs. In the author's opinion, these 22 hrs. represent a considerable waste of time. For shortening annealing time in these furnaces, we

³ Kikuta, T., "Effect of Thermal Treatment on Characteristics of Black-Heart Malleable Iron", TRANS. A.F.A., vol. 40, pp. 401-443.

⁴ Author's article in "NUMASH," no. 3, 1934.

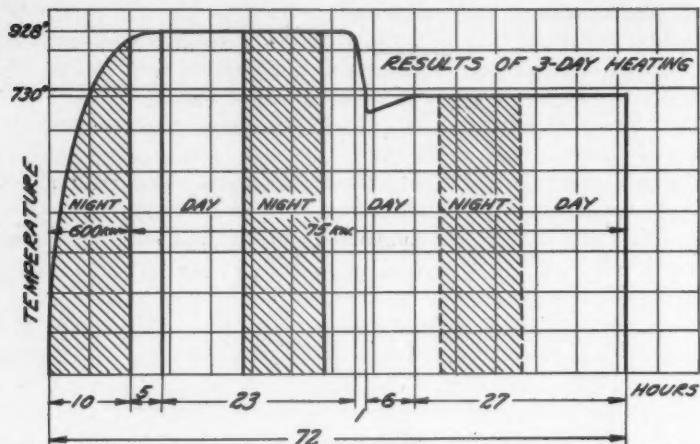


FIG. 6—THREE DAY CYCLE OF ANNEALING IN FURNACES OF THE INDUSTRIAL FURNACE CO.

would consider it sufficient to raise the temperature in the furnace above 930°C . (1705°F .) (say $970\text{--}980^{\circ}\text{C}$. or $1780\text{--}1795^{\circ}\text{F}$.), switching off the current directly the maximum temperature has been reached, and after a short holding period, cooling rapidly to a temperature say 750°C . (1380°F .), then slowly to 720°C . (1330°F .). Fig. 7 shows the proposed cycle plotted together with the existing one.

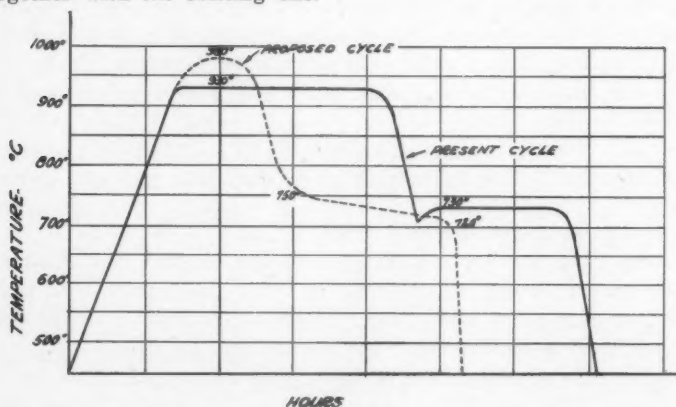


FIG. 7—SOLID LINE SHOWS CYCLE OF ANNEALING IN FURNACES OF INDUSTRIAL FURNACE CO., FOR 25-TON ELECTRIC FURNACES, IN ACCORDANCE WITH SCHEME B. DOTTED LINE SHOWS PROPOSED CYCLE OF ANNEALING FOR 25-TON ELECTRIC FURNACES IN ACCORDANCE WITH SCHEME D.

31. This cycle would give a considerable economy of electric energy, since the latter is used only during the period of heating of the castings and not as at present also during the second stage of graphitization. Such a cycle had been tested by the writer at the Gorky Automobile Works in 1932 (intermediate cooling was accomplished outside the furnace). The duration of the cycle was about 110-120 hours, on iron which was not uniform in composition, and contained chrome.

32. It would be much better to modify the design of the furnace so that rapid intermediate cooling of the castings would

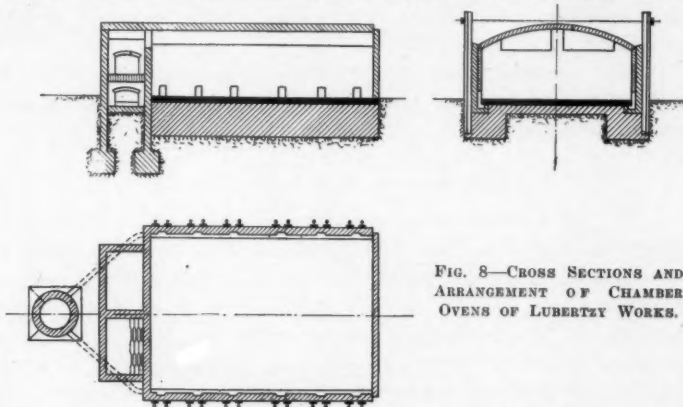


FIG. 8—CROSS SECTIONS AND ARRANGEMENT OF CHAMBER OVENS OF LUBERTZY WORKS.

take place in the furnace and the rate of decrease in temperature of both castings and furnace would be equal.

33. This method prevents the formation of cracks and scale when annealing without pots, since there is no necessity of exposing red hot castings to the open air. We would recommend air cooling the arch of the furnace by heat resisting pipes or by making the arch double and circulating cold air.

Chamber Ovens Fed By Ordinary Fuel

34. Chamber ovens fed by ordinary fuel are usually divided in two types: (1) Chamber ovens with stationary bottom, and (2) chamber ovens with moving bottom. Castings annealed in these ovens usually are packed in sand. As the presence of sand hinders rapid heating and cooling of castings, both types of the ovens may be referred to group (e) of our classification. Investigation of chamber ovens of Lubertzy Works (see Fig. 8), widely

used in Russian foundries, has shown that the temperature difference in the various parts of the oven is so great, that 25 hrs. or more (depending upon the capacity of the oven) are required for reaching the desired temperature of castings in the coldest places.

35. If high temperature of castings in the lower temperature portions of the furnace is desired, the temperature is unavoidably excessive in the normally high temperature places, which causes increased consumption of pots. The duration of annealing cycles in these ovens, in many cases, exceeds 100 hrs. because the characteristics of the ovens are not taken into consideration, and the annealing is carried out in accordance with scheme *A*, instead of scheme *D*.

36. Artificial intermediate cooling was introduced, but this did not give the desired result. Any reduction of annealing time was at the expense of incomplete annealing.

NEW DESIGN ANNEALING OVENS

37. If a considerable reduction of time and of fuel consumption is desired, the authors would consider it essential to secure most rapid and equal heating and cooling of castings in chamber ovens. Fig. 9 shows a similar oven of excellent design, worked out by the furnace laboratory of the Central Scientific Research Institute of Machinebuilding, in accordance with the author's instructions. However, in any event the elimination of

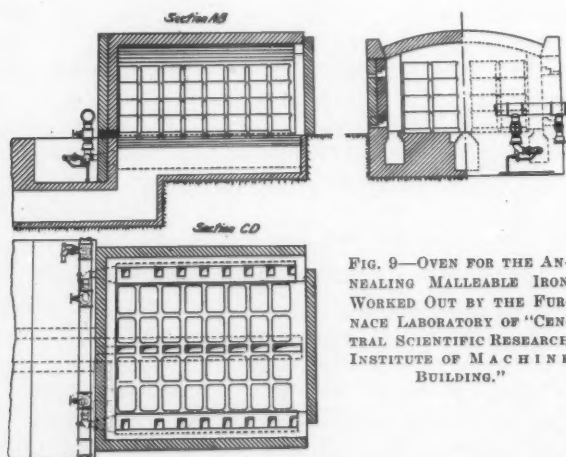


FIG. 9—OVEN FOR THE ANNEALING MALLEABLE IRON WORKED OUT BY THE FURNACE LABORATORY OF "CENTRAL SCIENTIFIC RESEARCH INSTITUTE OF MACHINE BUILDING."

packing material is of great importance in this problem. Fig. 10 shows the pots with sand seals suggested by us; these pots were tested in service (Lubertz Works, and others) and gave excellent results.

38. Annealing without packing material⁵ in ordinary chamber ovens considerably reduces the annealing cycle by more rapid and even heating and cooling, reduces the consumption of pots as

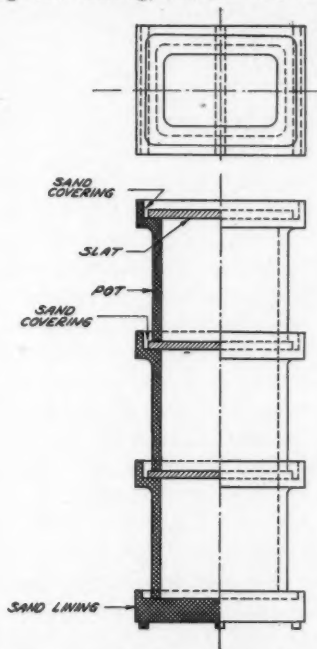


FIG. 10—POT FOR ANNEALING MALLEABLE IRON WITHOUT FILLING MATERIAL—
DESIGNED BY A. F. LANDA.

the number of runs per pot is increased. In the gas fired ovens, it is easier to obtain annealing of castings without any pots, since with a correctly selected annealing cycle the castings would be subjected to high temperatures for a considerably shorter time than usual. (The last instance refers in a still greater degree to tunnel kilns.)

39. In chamber ovens of satisfactory design, annealing without packing, should be carried out in accordance with the follow-

⁵ Landa, A. F., "Annealing of Malleable Iron without Filling Material,"
LITEJNOE DEL. no. 4, 1934.

ing schemes: *Scheme D*—for ovens with stationary bottoms, since these belong to the group (b); *Scheme A*—for ovens with movable bottoms, as these belong to the group (a). If chamber ovens were designed so as to accomplish intermediate cooling easily with sufficient speed, then annealing should be carried out in accordance with scheme A. By adhering to these conditions, an annealing cycle of a duration in many cases not exceeding the duration of annealing in electric furnaces, may be obtained for any chamber oven.

Tunnel Kilns

40. Further investigations were carried out by us with the tunnel kiln at Stalin Works (see Fig. 11),⁶ the duration of annealing in this kiln was 107.5 hrs., and at present the cycle is reduced to 57 hrs. and less. The kiln is 242.8 ft. long and contains 43 cars with castings. Investigations on the kiln have shown, that it might be referred to group (d). Heating and final cooling in this kiln are slow, whereas intermediate cooling is rapid. Therefore, the annealing cycle for this kiln should be selected in accordance with scheme A, but the time required for heating and final cooling of the castings should be reduced.

41. Fig. 12 shows the actual time temperature curve obtained in the kiln. To shorten the cycle, the maximum temperature of annealing has been increased from 870° to 970° C. (1600° to 1740° F.). Although the first stage of graphitization was well advanced before reaching the maximum temperature, and took 24 hrs., and the second stage of graphitization took 20 hrs., i.e., the total process of graphitization took only 44 hrs., the general cycle of annealing could not be reduced.

42. Investigations disclosed certain discrepancies between the process of annealing and the construction of the tunnel kiln.

(a) The castings are heated very slowly up to 900° C. (1650° F.) during 30 hrs. and while the desired temperature is reached, the first stage of graphitization is usually fully completed. The remaining time for the first and second stages of graphitization is utterly useless and rather injurious to the quality of the product.

(b) Final cooling after the completion of graphitization of the castings is extremely slow, taking about 25 hrs. Castings are usually taken out of the kiln at temperatures of

⁶ LITEJNOR DEL, nos. 7 and 9, 1933, no. 1934; NUMASH, nos. 8 and 9, 1933.

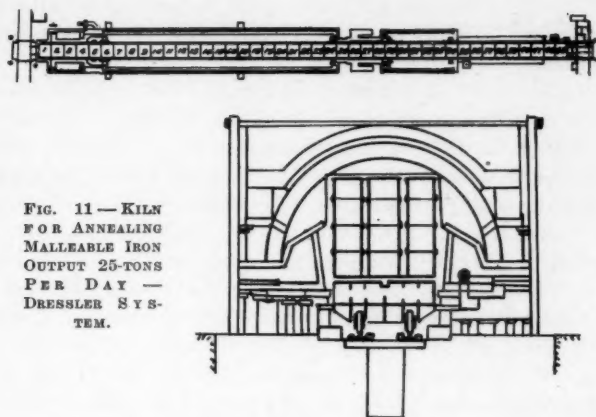


FIG. 11 — KILN
FOR ANNEALING
MALLEABLE IRON
OUTPUT 25-TONS
PER DAY —
DRESSLER SYS-
TEM.

350°-450° C. (660°-840° F.) which might bring about a brittle iron with the so-called "white fracture."

(c) The number of cars, in the zone of the second stage of graphitization is about a half that in the first stage, whereas at temperatures of about 970°-1000° C. (1780°-1830° F.) the first stage of graphitization in white iron of ordinary composition is completed in a few hours, and the second stage of graphitization requires a much longer time.

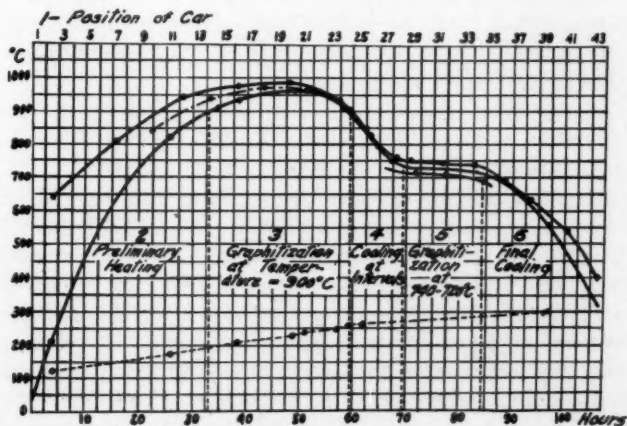


FIG. 12—TEMPERATURE CURVE OF DRESSLER KILN FOR ANNEALING CASTINGS OF MALLEABLE IRON.

(d) The kilns are constructed in accordance with fixed zones and it is not possible to adapt the cycle of annealing to different kinds of iron.

43. The time of annealing in tunnel kilns must be fixed in accordance with the length of that zone which is relatively the shortest, and the time in the other zones cannot then be altered.

44. In our case, the zone of the second stage of graphitization was the determining factor. A period of 20 hrs., equivalent to the introduction of a car every 2.5 hrs. was sometimes too short, and when the foundry tried to increase it by 5-10 hrs., the total time was increased by 25-60 hrs., *i.e.*, up to 177 hrs., although the other zones were already needlessly long at the rate of one push in 2.5 hours.

45. We suggested that annealing should be carried in accordance with scheme A, but to obtain the best results, the zones of the kiln had to be adapted to the iron which the works were annealing, and to shorten the time of heating and cooling of the castings:

(a) The supply of heat *to the first part* of the kiln should be increased by installing additional burners in the first zone; the number of cars subject to direct contact with kiln gases should be increased, to reduce the time required for the heating of the castings.

(b) The time required for intermediate cooling should be reduced by increasing the cooling of this part of the kiln by installing a metal portable cooler in the arch, which gives the possibility of selecting any correlations of zones of graphitization for any kind of iron.

(c) The second stage zone should be increased (about doubled) by means of reducing the final cooling zone from 9 to a maximum 3 cars.

46. When several of these modifications had been effected, heating to higher temperatures of the order of 1000° C. (1830° F.) took place even more rapidly than it had been expected, namely in 8-10 hrs. It made possible a further reduction of the time required for the first stage of graphitization, at the expense of higher temperatures. Instead of a portable artificial intermediate cooling, the works later totally dispensed with artificial intermediate cooling, which gave the possibility of moving natural intermediate cooling to any part of the kiln, so that a special cycle could be selected for any iron. In the end, final cooling was dis-

carded, and the castings were taken out of the kiln at 700° C. (1290° F.). We succeeded in reducing the cycle to 43 hours,⁷ and in adapting the kiln to any cycle in accordance with scheme D, Fig. 1.

47. When designing new tunnel kilns, doubts may arise whether muffles are needed, since they complicate the construction of the kiln, hinder the possibility of moving the zones of graphitization to obtain a special cycle for each iron, and, finally, delay the heating of castings in the kiln.

48. On the basis of a series of investigations, it may be presumed that owing to faulty construction of the kiln, the muffles are quite useless as elements isolating the pots and the castings from contact with the products of burning, and may only be useful as combustion chambers.

49. In our opinion, new tunnel kilns should be designed on the following principles:

(1) The zones of heating and cooling should be rather short and of constant length so that (a) heating to temperatures of 950°-1050° C. (1740°-1920° F.) would take 10-15 hrs. For this purpose, the quantity of heat admitted to this part should be correspondingly increased, and pots should be subject to the direct contact of more hot gases; (b) the zone of final cooling should be increased so that the duration of cooling would not exceed 5-6 hrs., and the rate of cooling would not be less than 100° C. (180° F.) per hr.

(2) The zones of the first and second stage of graphitization should be variable with regard to their length, so that a corresponding length of zones might be selected for each composition of iron and temperatures. For this purpose the intermediate zone of cooling should be made movable in two directions. It may be accomplished, for example, by installing a portable cooler in the arch, through the cavities of which cold air would pass.

50. In accordance with the above, new tunnel kilns for the annealing of malleable iron of most frequently used capacity should be constructed in the following manner:

51. Hearths for heating should be installed at a short space from the front entry gates of the kiln at a distance of about 16.4

⁷ The possibility of this considerable shortening of cycle of annealing was in a great part due to the fact that the composition of iron annealed by duplexing process has been considerably improved by lowering of carbon content and by decrease in silicon.

ft. instead of the 65-98 ft. of the present tunnel kilns. The burners should be placed through the whole length of the kiln on both sides up to the zone of final cooling. The zone of final cooling should contain not more than 2-3 cars instead of the 10-12 cars, as in current practice.

52. In the arch of the kiln should be installed portable artificially cooled sections with double walls, for the distance up to 3 and 4 cars. The place of installation of these sections depends upon the properties of annealed iron, and should be selected for each separate case. For iron of ordinary composition, they should be installed so that the length of the fourth zone would not be less than twice the length of the 2nd zone. The muffles are quite useless for gas kilns, and may be left in oil furnaces only in the zone with a temperature over 900°C . (1650°F .).

53. Figures 13 and 14 show two new schemes of kilns, worked out by the author and N. Dobrokhotoy on the basis of the principles of this paper: the first—with muffles, the second, without muffles. The cycle of annealing in such kilns may be reduced to a minimum and adapted to iron of any composition. For castings usually annealed in our foundries, the annealing may be easily reduced to 60 hours and less. The kiln would be much shorter and less expensive than the present tunnel kilns. Annealing pots would last much longer, the consumption of fuel would be reduced, and the cost of annealing would be much lower. In our opinion, the cycle of annealing in tunnel kilns should be best carried out in accordance with scheme *A*, which secures the shortest cycle in these conditions. However, in practice, the annealing may be effected also without artificial intermediate cooling, in accordance with scheme *D*. In this case, the cycle of annealing would be somewhat longer both in the new kilns, and in the present kilns.

CONCLUSION

54. The following conclusions may be accepted on the basis of this paper:

(1) There is no "accelerated" annealing of malleable iron, but there is an optimum cycle of annealing, selected in each separate case depending upon castings and ovens. "Accelerated" annealing may be obtained in any ovens, in accordance with a great number of practices governed by a very limited number of principles. It is only essential to

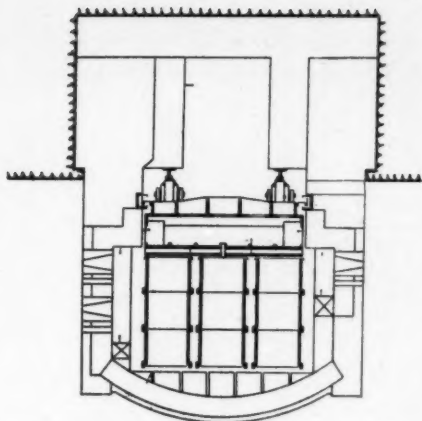


FIG. 13—NEW FURNACE DEVELOPED BY A. F. LANDA AND N. N. DOBROCHOTOFF.

select a correct practice for each oven. With a correctly selected scheme of annealing, a correct selection of time for the different periods of annealing, with the reduction of "non-productive" time (when the processes of annealing are not taking place), the cycle of annealing in any oven may be considerably reduced, and prove to be even shorter than is the case with the known electric furnaces.

(2) Ovens for the annealing of malleable iron should be designed to make them adaptable to the curves of annealing suited to the castings to be annealed. The alteration of time for one stage of graphitization should not cause excessive losses of time during other stages of graphitization. The time required for the heating and cooling of the castings is constant, and should as far as possible be used and taken into account so that during this time graphitization would take place, in order to shorten the total time of annealing.

(3) The construction of chamber tunnel kilns of the

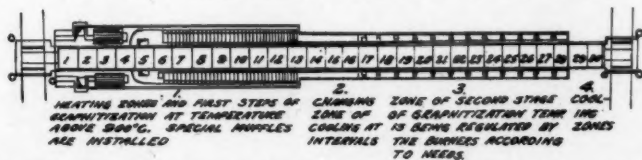


FIG. 14—OTHER TYPE FURNACE FOR ANNEALING MALLEABLE IRON, ACCORDING TO DESIGN OF A. F. LANDA AND N. N. DOBROCHOTOFF.

existing type should be suspended and the modifications worked out by us should be introduced in the existing ovens as well as in the ovens under construction.

Studies on the Solidification and Contraction in Steel Castings—V. Contraction Stresses*

BY CHARLES W. BRIGGS**, WASHINGTON, D. C.

Abstract

This paper discusses the fundamental underlying principles of contraction in steel castings. The following subjects are considered in detail: (1) Plastic and elastic deformation at elevated temperatures; (2) Stress centralization; (3) The magnitude of contraction stresses at hot tearing temperatures and at room temperatures; and (4) The effect of solidification on contraction stresses.

1. There are four fundamental conditions that make up the underlying principles of a study involving contraction stresses in steel castings. These may be listed as follows:

- (1) There are no contraction stresses in a freely contracting cast bar.
- (2) In a stressed cast bar the resulting stresses are independent of the length of the bar.
- (3) Stress magnitudes vary as to the inverse ratio of its cross-section in which they appear.
- (4) Internal stresses in a casting are proportional to its modulus of elasticity, to its coefficient of contraction, and to the differences of temperature involved.

2. In order that the subject of contraction stresses be understood better it would seem advisable to dwell at some length on the above factors effective in stress concentration and stress magnitude.

3. The simplest of all castings is that of a round bar with a uniform section throughout and which is allowed to contract freely. Such a bar would be free from contraction stresses. If, however, the casting were circular in shape, such as for example (Fig. 1), contraction stress would be pronounced and their magnitude would largely depend on the rigidity of the inner core of sand. The greater the hindered contraction the greater are the stresses acting on the casting.

4. At any one time during the cooling of this casting from

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the solidifying temperature to room temperature the stress application on the section l (Fig. 1) is equivalent to

$$S_l = E \frac{\Delta l}{l}$$

where E is the modulus of elasticity of the material and Δl is the change in length of l that has taken place during the contracting of the steel. This condition also is true for a longer section L

$$S_L = E \frac{\Delta L}{L}$$

but $L = kl$ and $\Delta L = k\Delta l$

$$\frac{\Delta L}{L} = \frac{k\Delta l}{kl} = \frac{\Delta l}{l}$$

$$\therefore S_l = S_L$$

5. Hence, the resulting stresses are independent of the length of the circular bar and no greater in long bars than in short ones. This point is not universally appreciated in the foundry since a casting is seldom made that embodies only those features of uniform section and therefore uniform casting rates. It is a good point to remember, however, as greater emphasis can then be placed on the design of a casting since it is known that the contraction stresses acting on a casting are independent of the length.

6. A slight change in the casting of Fig. 1 will bring out other features in the application of stresses. In Fig. 2 a large bar of cross-section A_1 is joined to a small bar of cross-section A_2 by heavy end sections. It is assumed that these end sections will prevent the casting from movement so that it cannot bend or warp. Bar A_2 will completely solidify before the large Bar A_1 ; thus a temperature gradient is produced within the casting. This temperature gradient is responsible for a setting up of stresses in the

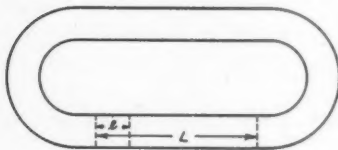


FIG. 1

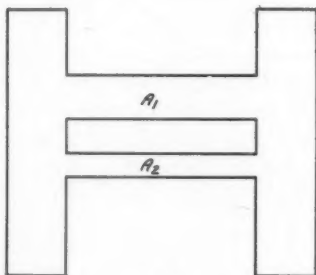


FIG. 2

casting since this amount of solid contraction depends on the temperature and the hindered contraction. As the two bars are joined together, and are therefore not allowed to contract freely, a compression stress will be developed in the large A_1 bar and a tension stress in the small A_2 bar. Since the stress system must be in equilibrium, the following conditions are obtained:

$$S_t A_2 = S_c A_1 \quad \begin{array}{l} S_t = \text{tension stress} \\ S_c = \text{compression stress} \end{array}$$

or

$$\frac{S_t}{S_c} = \frac{A_1}{A_2}$$

7. It is thus shown that the magnitude of the stresses is in an inverse ratio to the size of the cross-section in which they appear.

8. This general line of reasoning can be carried out more fully as has been done by Heyn^{1*} to show the relationship of the internal stresses to the solid contraction.

9. Again referring to Fig. 2 when the bar with the cross-section A_1 has completely solidified at temperature t_1 the smaller bar, cross-section A_2 has already solidified and is at a lower temperature, t_2 , and therefore has been contracting. If both bars were free and not held together by the heavy connecting section, bar A_2 would assume the length

$$L = l [1 - a (t_1 - t_2)]$$

where l is the original length of the bar upon complete solidification and a is the coefficient of contraction. Since the bars are held together by the heavy sections the two bars must have a mean length l_h , and the large bar A_1 would be under tension stress S_t and the small bar A_2 under a compression stress S_c , with the conditions of equilibrium as follows:

$$A_2 S_t = A_1 S_c \quad (1)$$

$$S_t = E \left[\frac{l - l_h}{l} \right] \quad (2)$$

$$S_c = E \left[\frac{L - l_h}{l} \right] = -E \left[\frac{l_h - L}{l} \right] \quad (3)$$

where E is the modulus of elasticity of the steel, and the stresses do not exceed the elastic limit.

$$\text{But } L = l [1 - a (t_1 - t_2)] \quad (4)$$

* Superior numbers refer to references listed in the Bibliography at the end of this paper.

By substituting values of equations (2), (3) and (4) in equation (1) it follows that

$$l_h = l \frac{\{A_1 - A_2 [1 - \alpha (t_1 - t_2)]\}}{A_1 - A_2} \quad (5)$$

Putting the value of l_h in equations (2) and (3) it is found that

$$S_t = \frac{E A_2 \alpha (t_1 - t_2)}{A_1 - A_2} \quad (6)$$

$$S_c = \frac{E A_1 \alpha (t_1 - t_2)}{A_1 - A_2} \quad (7)$$

10. From the equations (6) and (7) it can be readily seen that the internal stresses are proportional to the modulus of elasticity, to the coefficient of contraction, and to the difference of temperature.

11. So far it has been assumed that the bar shapes have undergone changes of only an elastic nature. As long as the internal stresses cause only elastic deformation, the stresses will be temporary; however, when permanent deformation exists then permanent stresses are left in the metal.

PLASTIC DEFORMATION

12. The casting as presented in Fig. 2 will again be considered. Because of the difference there exists between the diameters of bars A_1 and A_2 they will cool from the solidifying temperature to room temperature at different rates. Thus at any definite time during cooling, the temperatures of the two bars will be different. The temperatures will, however, approach each other and equalize at room temperature or perhaps at some elevated temperature. Fig. 3 represents a typical curve showing the unequal cooling conditions of the two bars. It will be noticed that the differences will be the most pronounced at the higher temperatures. It has already been pointed out that the temperature differences of the two bars create internal stresses, which in this case, are so great that the elastic limit of the material is exceeded. To exceed the elastic limit is not a very difficult condition to fulfill since steel at very high temperatures has exceptionally low elastic limits and all deformation taking place is principally plastic.

13. The mold chilling effect and the variation in cross-sectional areas cause the wide difference in temperature. Since the contraction of the steel is closely aligned with the temperature the normal rate of contraction of the two bars will be somewhat

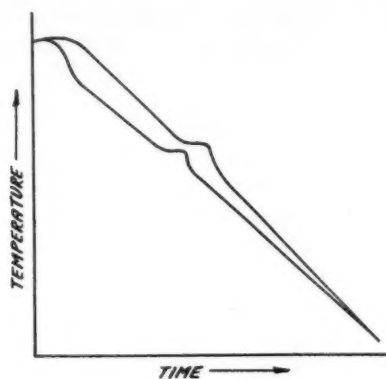


FIG. 3

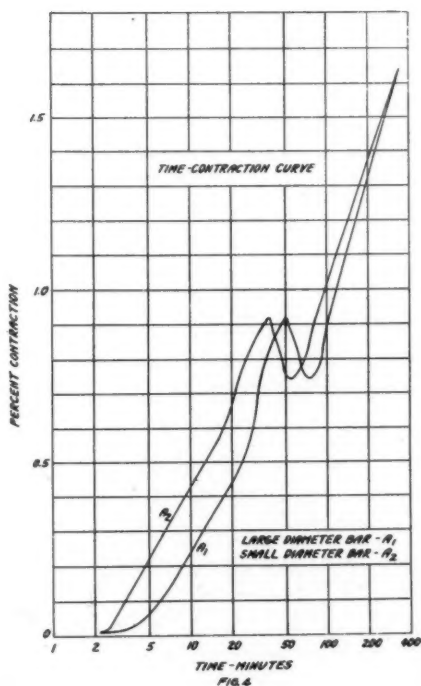


FIG. 4

different. A possible condition that may exist is shown in Fig. 4. The data plotted here represents the time-contraction characteristics of each bar separated instead of being joined together by the flange construction. Here again the most noticeable variation comes shortly after the steel has solidified. As this portion of the curve is rather interesting, it is enlarged as in Fig. 5.

14. It will be supposed that the flange joined bars have plastically deformed at a definite time t_1 and that the lengths of the bars have compromised on a mean length B so that at the definite time t_1 the large diameter bar has been plastically compressed by the amount CB and the small diameter bar has been plastically stretched by the amount DB . Thus at t_1 the two bars have the same length but are at different temperatures. Now as the cooling time proceeds from t_1 the bars continue to contract and elastically deform so that at the time t_2 the tendencies for the respective lengths are represented by the lines BE and BF where BF corresponds to the contraction of A_2 and BE corresponds to the contraction of A_1 . These lines indicate the extensions which would take place after passing time t_1 if the bars were separate instead of being coupled. At time t_2 , then, the bars tend to differ by an amount FE , and they compromise at the mean value B' .

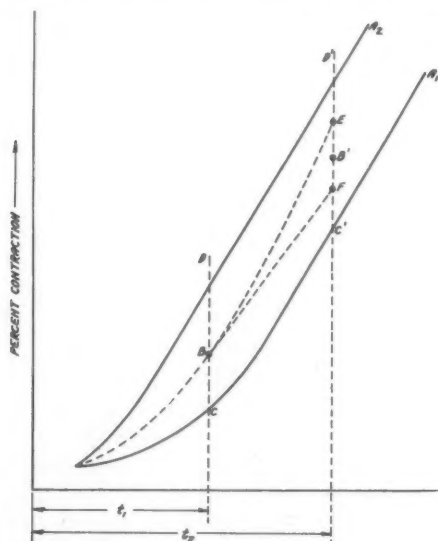


FIG. 5

Thus, the large diameter bar A_1 is in compression corresponding to the amount B'E while the small diameter bar A_2 is in tension corresponding to the amount B'F.

15. The above conditions do not represent entirely the actual conditions found in the cooling of steel. For one thing, there is no clear cut temperature at which deformations change from the plastic to the elastic state. In fact experimentation has shown that stresses causing initial yielding at low temperatures decreases about linearly with increasing temperature, but become nearly independent of the temperature when the melting point is approached. Thus metal crystals have a small but finite elastic limit at temperatures approaching the melting point.

16. Conditions presented in Fig. 5 do, however, correspond most closely to conditions encountered in practice and explains the presence of permanent stresses within the casting.

17. In the preceding paragraphs, the discussion was limited to stresses that were developed because of cross-sectional differences in the metal casting. It should also be pointed out that the mold conditions can cause stress conditions similar to those above. The manner in which mold conditions operate to bring about internal stress has been enumerated many times by authors writing on the subject of the Design of Steel Castings. It is therefore sufficient to say that internal stresses arise due to the prevention of normal contraction by the rigidity of sand molds and cores. It has been shown in a previous paper² in this series that the universally used "patternmakers shrinkage" is not the normal free contraction of steel and that castings manufactured on this basis have, in the as cast condition, internal stresses present.

18. It may be helpful if further consideration were given to an actual case involving stress application due to mold resistance. A bar with a flange on either end molded in a hard dry sand may suffice as an example. It is evidence that the sand between the two flanges will prevent the bar from contracting normally. The bar tends to contract toward its center but the sand pressing against the inside faces of the flange prevents it from so doing and hence stresses are built up in the casting, the bar portion being under a tension stress.

19. Now one of two things can happen; (case 1) either the casting tears at the junction of the bar to the flange, or (case 2) it cools to room temperature in one piece but its overall length is much greater than that of a plain bar without flanges.

20. Why should the casting tear as suggested in case (1)? The tension stress that was developed in the bar by the flanges will concentrate at the weakest section, which in this case was the junction of the flange to the bar. The stress was so great, since the hard mold prevented any movement of the flanges, that plastic deformation could not take place rapidly enough and consequently the physical properties of the metal were exceeded and hot tears formed.

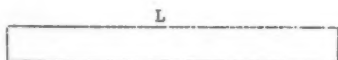
21. In case (2) it is evident that stress centralization did not occur in the magnitude of case (1) since the casting did not tear. But the casting was hindered from contracting normally and hence was under stress, as has been conclusively demonstrated². The magnitude of this stress depends on the rate of the stress application, or to put it in another way, the stress depends on the rate of plastic deformation.

$$S = K \frac{d\rho}{dt}$$

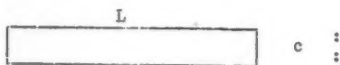
where S is stress and ρ is the plastic deformation, or elongation, or if one prefers, the hindered contraction.

22. Perhaps a diagrammatic representation of the principles involved would present the case more clearly.

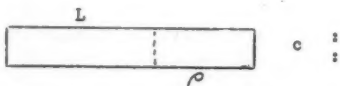
- I. Length of the bar immediately after solidifying.



- II. Length of the bar at $t^{\circ}C$ when contracting freely.



- III. Length of the bar at $t^{\circ}C$ when hindered from contracting freely.



23. In diagram (I) the bar takes on a definite length corresponding to the dimensions of the mold. If the bar were then allowed to contract freely its length would be as illustrated in (II) where in c represents the amount of free contraction. If, however, the bar were not allowed to contract freely, such as has been done above where flanges were placed on the ends of the bar, then ρ would represent the amount of elongation or plastic deformation

that has taken place. The magnitude of p depends on the amount of stress acting on the bar and the time in which it is effective. Plastic flow of a metal occurs only as long as there is a force acting on it and the rate at which it takes place depends on the magnitude of the force. Thus, when metal is cast under conditions that tend toward high resistance to contraction, the magnitude of the stresses acting on the casting is high, the rate at which they build up is fast, and the amount of plastic deformation that takes place is large. If, however, the resistance to contraction is not high, then the other factors bearing on it will be correspondingly lower.

24. The above has been set forth to explain some of the more important points of plastic deformation. It should be added that if at any time the cooling cycle of the stressed casting could be arrested, at some high temperature, the magnitude of the stress would be progressively less with time, since plastic deformation of the metal would reduce the stress to zero. From this it can be seen that the cooling rate of the metal is important in considering the magnitude of the stress. In two hindered contracting castings acting under like conditions, except for the cooling rate, the fastest cooled casting will build up the highest stresses.

STRESS CENTRALIZATION

25. It was stated under the discussion of the flanged bar above that the casting would tear at the junction of the bar and the flange. The reason for this is two-fold: (1) this section is at the highest temperature and therefore the weakest since it was the last point in the casting to solidify; and (2) corners are excellent points of stress centralization. All abrupt changes in section, sharp corners and casting irregularities are potential positions of stress concentration. When stresses arising from hindered contraction of a large casting concentrate at one point, it is easy to see that stresses may build rapidly. It is because of this condition of stress centralization that many foundrymen have looked skeptically at the statement made previously that contraction stresses arising in a casting are independent of the casting length since they are able to point to the fact that many long castings fail while short castings do not. This failure in long castings is not the result of greater stresses developed because of their length, but it is due to the fact that these stresses may centralize in one place due to hot spots, sharp corners, et cetera, and the combined stresses centralized in a long casting will be

much greater than the combined stresses centralized in a short casting.

26. How is it possible to prevent stress centralization? Proper casting design will limit the concentration of stresses. Castings should be so designed that they will embody the minimum number of abrupt changes in section, sharp corners, skin irregularities, and isolated hot spots. Brackets are used to a considerable degree today to distribute stresses from sharp corners over a thin web of steel that has quickly solidified, and hence, because of its greater strength, would absorb the stresses, preventing casting failure. Brackets are, however, not always successful, for in the final analysis they add but little strength to the casting and at best are weak tie rods to adjoining sections, since the brackets themselves are at the same temperature as the skin of the casting. A judicious use of good casting design principles is by far the best method of preventing centralization of stresses.

27. In the preceding pages, it has been pointed out that contraction stresses may result from the differential cooling of metal sections and from the action of the mold hindering the normal casting contraction. It should be stated that there may be a combination of both stress forming methods arising within the casting.

THE MAGNITUDE OF CONTRACTION STRESSES AT HOT TEARING TEMPERATURES.

28. Probably the most serious defect with which the steel casting manufacturer contends are cracks, and of these the hot tear crack is the most prevalent. Prior to 1928 much had been said concerning the cause of hot tearing and how to prevent it, but little was known of the actual conditions of hot tearing, such as the cracking temperature or the magnitude of the stresses causing hot tearing. In 1928 Körber and Schitzkowski³ produced hot tears in flanged bars by hindered contraction and decided that the critical temperature at which hot tears are most liable to be formed was about 1250 to 1300° (about 2280-2370° F.). They did not, however, measure the stresses on the bars at the time of hot tearing. In 1932 the author and Gezelius made a study of the stress acting on a bar during hindered contraction. These bars did not break under the hindered contraction applied as they were so designed as to prevent points of stress centralization.

Since the bars did not break this work did not show the actual amount of stress necessary to cause hot tears at the hot tearing temperature, but it did show the load carrying ability of steel under hindered contraction.

29. In 1936 Hall of Woolwich Arsenal⁴ presented data on the strength and ductility of steel at temperatures near the melting point. In the region of 1250 to 1300° C. he showed that the ultimate stress necessary to cause failure in one inch bars averaged, for cast carbon steel, from 1700 pounds per square inch at 1300° C. to 2500 lbs. per sq. in. at 1250° C. There is no indication from this work that the temperature range, 1250 to 1300° C. more conducive to the formation of hot tears than any other temperature range. In fact the temperature-ultimate stress curves show nearly a straight line relation in that there is practically a uniform increase in the ultimate strength as the temperature drops.

30. A stress of 2000 lbs. per sq. in. is quite large considering that in the case of cracked castings it presumably is developed by hindered contraction.

31. It was shown in the second and fourth publications of this series^{2, 5} that in a 0.35 percent carbon steel in the temperature range 1300-1250°, the amount of stress developed on a bar of 2 square inches with various types of hindered contraction was as follows:

Stress, lb. per sq. in.		Type of Hindered Contr.	% Contr. at Room Temperature
1300°C.	1250°C.		
230	350	E spring	1.7
500	700	G spring	1.0
700	1000	C spring	0.5

32. The above figures would indicate that even under the most drastic conditions of hindered contraction the stresses developed during the 1300-1250° C. temperature range would not be sufficiently high enough to cause failure since Hall shows evidence of ultimate strengths in the neighborhood of 2000 pounds in this temperature range. Notwithstanding all this it is known that castings do fail and the hindered contraction that is active may not be much greater than that developed by the E spring as listed above. The realization of this fact leaves two points for consideration; either the critical cracking temperature has been selected at too low a temperature, or else stress centralization is responsible for the apparent discrepancies so that tearing does

occur when most of the casting cools to the 1250-1300° C. critical cracking range.

33. A study of hot tear fractures as they actually occur in the foundry will show that there has been little or no elongation or reduction of area of the steel prior to fracture. Hall has shown that all the steels he tested had an elongation value at skin temperatures below 1300° C. In some of the low carbon steels (below 0.15 per cent carbon) ductility, as measured by elongation, was found to exist at temperatures approaching 1400° C. In fact all the steels he studied had a 5 per cent or greater elongation when fracture occurred at 1250° C.

34. If these points are considered it would seem reasonable that the critical cracking temperature range was above 1300° C., perhaps between 1300 and 1400° C.

35. In a study of the tensile strength at elevated temperatures of cast steel, that had previously cooled to room temperature, Piwowarsky, Bözić and Söhnchen⁶ reported tensile strengths of 250 to 300 pounds per square inch at 1250° C. These figures are more in line with the stresses developed by hindered contraction, but it is felt that not too much significance should be placed on Piwowarsky's figures since the rate of testing was considerably slower than that used by Hall and temperature gradients as are usually found in castings were not present.

36. It was suggested that perhaps, because of stress centralization, tearing occurs when most of the casting cools to the 1250-1300° C. range. It is quite possible that such may be the case since, as has been shown, differential cooling and hindered contraction due to the mold will set up stresses that will concentrate at a hot spot in the casting with the result that the casting will tear. The hot spot may have a temperature approaching 1400° C. while other parts of the casting will be at temperatures of 1250 to 1300° C. In such a situation, stresses of 250 to 500 lbs. per sq. in. could arise through hindered contraction which, if concentrated at the 1400° hot spot would be, according to Hall's experiments, a sufficient load to cause tearing.

37. Thus, it is possible that small tension stresses as developed by hindered contraction are responsible for hot tear formation providing that the hindered contraction present is greater than that normally allowed under "patternmakers shrinkage".

38. A study of hot tearing as exhibited in various castings is responsible for a realization that tearing in some cases takes

place when the responsible stresses are even lower than that which appears to be necessary to cause failure by tension. It is often evident that failure has been due, from the very nature of conditions involved, to shear stresses. For example, Fig. 6, shows a small casting made in green sand that consisted of 4 one inch diameter bars having been run from a larger block section. The bars were 30 inches long and free at the end. It will be noticed that the two outside bars were completely torn away from the block while the two inner bars were solid to the block and had to be cut from it. The bars contracted towards the block and the block contracted towards its center. The hindered contraction due to the green sand was necessarily low, yet the shear stress developed, because the contracting of the block, was sufficient to cause the outer bars to be torn from the block. From the very nature of things, it can be seen that the resulting shear stress was very low. This would indicate that steel at these very high temperatures has very little resistance to shear stresses, in fact, much less resistance than it has to tension stresses. Hot tearing is not so much a result of tension stresses as it is a product of shear stresses. If such is the case, an entirely different light is brought to bear on the problem and a knowledge of the properties of steel under tension would not therefore show the magnitude of the stresses causing hot tear formation. Some attempt to increase the knowledge along this line is undoubtedly necessary. It should be added, however, that the entire problem of stress magnitude at the time of hot tearing is undoubtedly tied up with (1) the rate of stress application, (2) the centralization of stresses, and (3) the nature of the acting stress.

39. Before leaving the subject of stress magnitude at high temperatures, it might be well to call attention to a question that is often stated as follows: In order to relieve casting stresses, it

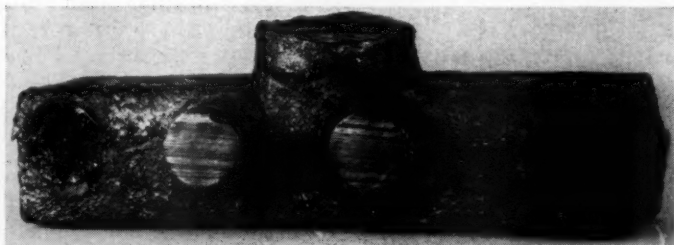


FIG. 6

is necessary to heat the casting to fairly high temperatures. In view of this fact, why is it that there is any stress at all on the casting at these high temperatures? The answer is obvious in that the casting sections are continually in stress under hindered contraction conditions. Though plastic deformation does take place to relieve this load, the time that the casting remains at any one temperature is not sufficient to allow for a complete equilibrium of conditions to be obtained; hence, the casting sections are always under stress.

MAGNITUDE OF STRESS AT ROOM TEMPERATURE

40. A very definite estimate of the magnitude of stresses that may be found in steel castings has been presented in the second and fourth reports of this series^{2, 5}. These investigations presented in detail the stress conditions acting on various carbon and alloy steels under hindered contraction. Summarizing this work in a very general manner the following conditions are found to prevail on a section of a cross-sectional area of two square inches at room temperature:

% Hindered Contraction	Stress, pounds per square inch
0.5	11,000
1.0	7,000
1.7	2,700
2.4	0

41. If a casting contracts only one per cent during cooling from its solidification to room temperature, then a stress of approximately 7,000 pounds per square inch will be acting on the casting due to hindered contraction alone. If, however, the casting is removed from the mold, hindered contraction can no longer be effective, and the stress due to hindered contraction is removed. For example if a flanged bar cooled in a hard mold so that at room temperature it had contracted only one per cent a stress of 7000 lbs. per sq. in. would be acting along the bar due to the action of the mold exerting a force against the inside faces of the flanges. If the sand is removed, the force is removed, and the casting is no longer under stress from hindered contraction. This does not necessarily mean that the casting is entirely free from stress. It may have locked up stresses that are present in large magnitudes. This fact is well known from practical observations of two types.

Large castings that have been shaken out and allowed to remain on the foundry floor have cracked badly if the room temperature has dropped considerably. In another case, castings that have been pickled may show surface cracking caused by high stress conditions⁷. These high stresses are developed by unequal cooling of the metal sections. One section may be expanding during the critical range while another section is contracting. This may mean a difference of as much as 0.3 per cent movement as according to charts prepared in the 2nd and 4th reports^{2, 5}. Since these sections are tied together, movement is not possible; hence, stresses of large magnitude are tied up within the casting. If 30,000 lbs. per sq. in. was assumed as the elastic limit, an assumption which is not at all unreasonable, and the modulus of elasticity 30,000,000 pounds, then a resistance to a movement of 0.1 per cent would be equivalent to a stress equal to the elastic limits at room temperature conditions. This would be somewhat different at critical range temperatures but a general indication is given of the stress magnitudes that may exist when there is a resistance to contraction or expansion of 0.3 per cent at critical range temperatures.

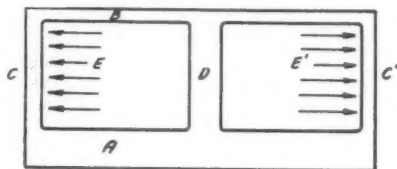
42. There are two methods by which it is possible to prevent locked up stress from reaching such high magnitudes. One method necessitates the use of casting design, or controlled solidification to prevent sections from having such wide temperature variations. The other method is to produce castings with alloy combinations that show only a small expansion during the critical range. This latter method has been used in a practical way with good results. A manufacturer found that he was having difficulty in producing a certain casting because of cracking at apparently low temperatures. He changed to a molybdenum cast steel, because its expansion during the critical range was very low, and produced perfect castings.

43. From the above discussion it can be concluded that a casting in the mold at room temperature may be stressed as much as 10,000 lbs. per sq. in. by hindered contraction due to mold conditions. The casting may also be under stresses the magnitude of which may mount as high as the ultimate tensile strength of the steel and in this case the residual stresses are caused by temperature gradients.

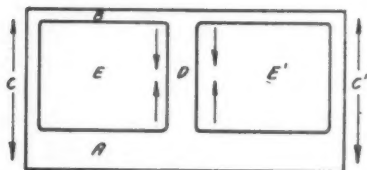
44. Considerable information on stress characteristics may be learned from a continued study of the ordinary commercial

casting, especially if it shows failures due to cracking. The location of the crack would give indications of the manner in which the stresses operated. A simple casting whose cross-section had the appearance as illustrated in Fig. 7, may be used as an example. A large number of castings have such a type cross-section only perhaps in more elaborate details.

45. Suppose (Case I, Fig. 7) sections C and C' are found torn away from Section A, then it may be correctly assumed that real hard cores were used at E and E' causing hindered contraction, load application, and plastic deformation due to temperature gradients in varying sections, and finally stress centralization resulting in a shear stress causing cracking. Section D did not break from A because it is cooled at somewhat the same rate as A.



CASE I - FIG. 7



CASE II - FIG. 8

However, B might break from D such as C did from A. If, however (in Case II, Fig. 8), cores E and E' were very collapsible and stresses were not formed by hindered contraction due to core resistance, then it is quite possible that a tear will be found where D joins A. In this case, Fig. 8, stresses are built up by hindered contraction due to metal section differences. Sections C and C' are cooling faster than section D and consequently contracting more than Section D; thus sections C and C' are under tension while D is under compression stresses. The tear occurs at the hot spot which is the junction of the sections D and A.

46. Suppose, however, the castings as illustrated in Figs. 7 and 8 cooled to room temperature without cracking. It was found

by experimentation that by cutting section D (Case II), the gage length marked in this section increased and it was necessary to apply a load of 1,000 pounds to return the gage length to its former length. This indicates that a compression stress of 1,000 pounds was acting on section D when the casting was at room temperature.

47. Section D in Case I was given a like treatment but it was found that the gage length did not move to a measurable amount and the casting presumably was without stress. This showed that all sections of the casting plastically deformed and when the casting was removed from the mold, the stresses due to mold resistance were relieved and the casting apparently free from stress. (The word "apparently" was inserted because the experiment did not measure the stresses in section A or section B).

48. It might be worth pointing out that it is practically impossible to produce even a freely contracting round bar that is completely free from internal stress due to temperature gradients. Since such a bar cools from the outside toward the core, circumferential tension and compression stresses are always present.

49. The above experiments point out that if a stress analysis is made of castings, more familiarity with casting stresses can be obtained.

EFFECT OF SOLIDIFICATION ON CONTRACTION STRESSES

50. At several places in the preceding discussion, mention was made to hot spots within castings and the part they played in the centralization of stresses. It was also suggested that if these hot spots could be eliminated a casting would be less subject to hot tear formation. By controlled directional solidification, castings may be produced so that no adverse temperature gradients and hence no pronounced hot spots will be formed. Since large adverse temperature gradients are potential stress formers, anything that can be done to reduce adverse temperature gradients within a casting would likewise reduce the stresses acting on the various sections of the casting. Other investigators have reported the difficulty that arises from trying to form hot tears in castings that have a uniform cooling rate. Thus castings that have a controlled directional solidification not only are more properly fed but are less prone to hot tear formation.

51. Besides eliminating hot spots and reducing adverse temperature gradients, there is also the possibility that a casting pro-

duced by controlled directional solidification may be subject to lower hindered contraction stresses due to mold resistance than are found in the same casting produced by the orthodox solidification methods.

52. For example, a pattern was designed that would be subject to considerable mold resistance and castings were produced by the orthodox manner and by Batty's partial reversal controlled directional solidification method. Fig. 9 shows a plan view of the pattern and Figs. 10 and 11 illustrate the two methods as molded. The directional solidification casting was rotated through an angle of 30 degrees immediately after pouring. The castings were sectioned and it was found that both methods produced solid castings.

53. Accurate measurements were taken as to the amount of contraction that took place; these are listed as follows:

Casting Conditions	Mold Conditions	% Contraction	Hindered Contraction lb./sq. in.
Orthodox	Dry sand	1.06	5700
C. D. S.*	Dry sand	1.29	4350
Orthodox	Green sand	1.56	2975
C. D. S.	Green sand	1.59	2800
C. D. S.	Green sand, furnace cooled	2.26	....

54. The column "Hindered Contraction, lb./sq. in." was obtained from the curve, Fig. 12 drawn from data presented in the second report of this series (2) and is included to show the general nature of the stresses that can be obtained by hindered contraction due to mold resistance at the time the casting is at room temperature and still within the mold.

55. It may be noticed from the table that in the dry sand practice the two casting methods had rather widely spread contraction results. The reason for this is that in the orthodox method a more liberal use is made of feeding heads. These protuberances increase the surface area of the casting, and act as extended flanges with the result that there is more mold resistance on the casting and hence the casting has less opportunity to contract. The orthodox casting including heads and gate weighed 40 per cent more than the controlled directional solidification casting.

56. When the two casting methods were produced in green sand there was very little difference in their total contraction and

* Controlled directional solidification.

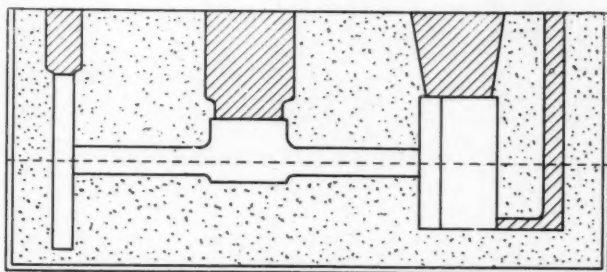
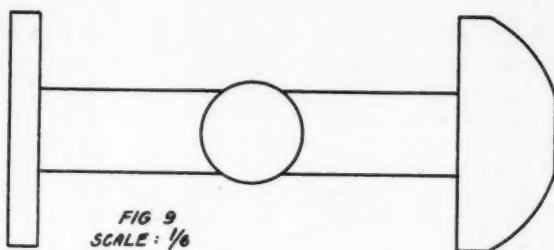


FIG. 10

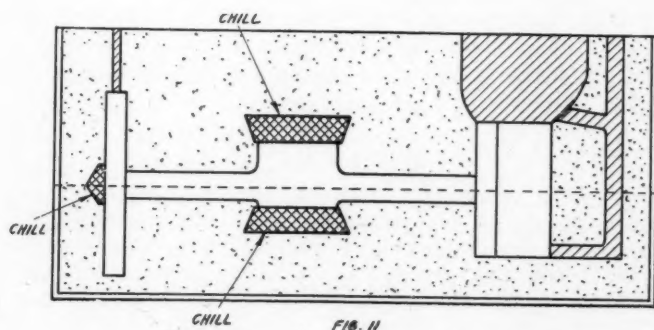


FIG. 11

STRESS ON 0.35% CARBON STEEL
AT ROOM TEMPERATURE

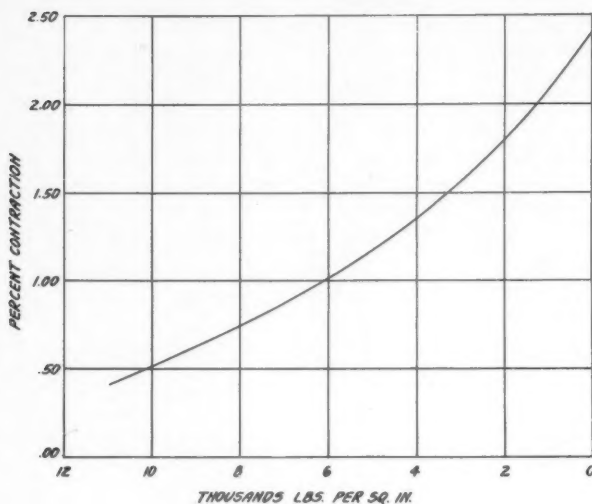


FIG. 12

the stresses developed were roughly a half of those attained when the dry sand practice was used.

57. If a casting is shaken out of the mold soon after pouring and placed in a heated furnace and slowly cooled to room temperature, then contraction values equivalent to a freely contracting bar can be obtained, and the casting would be practically free from all types of contracting stresses.

58. It therefore may be said that the method of solidification influences the action of contraction stresses.

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A Study of Non-Ferrous Molding Sands

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Abstract

The authors undertook a study of molding sand used in non-ferrous foundries for the purpose of correlating test figures obtained, from samples submitted, with other foundry variables such as molding methods, casting weights, type of metal used, etc. The final results cover test and other data obtained for sands used to produce aluminum, brass, bronze, copper-nickel, and copper castings. The authors summarize their findings under the following heads: kind of sand used, method of molding, sand preparation, flask equipment, mold facings, casting finish, green strength, deformation, dry strength, moisture, permeability and fineness. The authors found the natural sands were used exclusively for aluminum and brass castings, that mechanical sand preparation equipment is used extensively in non-ferrous foundries, that few non-ferrous foundries rent the flask equipment, that in the majority of foundries making aluminum castings the permeability ran less than 10 and was between 10 and 20 for brass and bronze sands, that 7.5 lb. per sq. in. was about average green compression strength for non-ferrous sands, that dry strength varies considerably, and that pan material was very prominent in the majority of samples submitted. The authors also evolve formulae for calculating permeability and the approximate moisture content required.

1. Testing molding sand to determine its physical properties is very useful when information is on hand as to the casting results obtained with different physical properties of sand. Such information can readily be compiled by keeping a record of sand test figures and casting results. Therefore, it is as essential to test sand when good castings are obtained as when poor castings are obtained. Comparing ones own sand test figures with other foundries is most educational. Study sand test figures of sands that are used for entirely different castings. It will give an idea of how the various sand test figures are varied to take care of

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different molding methods, metals, casting weights and other conditions.

2. A study of molding sand used in non-ferrous foundries was undertaken to correlate sand test figures of sand as used in various non-ferrous foundries with molding methods, casting weight, metals and other foundry conditions.

3. Sand samples were obtained from 13 non-ferrous foundries. A questionnaire was filled by foundries submitting sand samples giving information on conditions under which the sand was used and also the nature of metal and casting weight produced in the sand. Table 1 shows the data requested.

Table 1

QUESTIONNAIRE SENT TO NON-FERROUS FOUNDRIES.

Sand Sample No.

Natural Sand. Synthetic Sand.

Sand Mixed by: Sand Cutter. Pug Mill. Shovel.

Muller. Aerator.

Is Sand Riddled Before Placing on Pattern? No. Yes.

Size of Riddle.

Sand Used on Floor. Sand Used in Sand System.

Sand Rammed by: Hand. Hand Squeezer. Jolt.

Squeezer-Jolt.

Size of Flask, Length, Width and Depth: Minimum. Maximum.

Are Sides of Flask Vented? Yes. No.

Mold Dust Used:

Mold Wash

Thickness of Casting Wall: Minimum. Inches. Maximum. Inches

Predominating Casting Wall Thickness: Inches

Weight of Casting Sand Is Prepared for: lbs. to lbs.

What Is Casting Used for:

Temperature of Metal Poured: Degrees Fahr.

How Measured:

Approximate Analysis of Metal:

Sand Casting Finish: Smooth. Medium. Rough.

Samples of Sand Submitted by:

.....
(firm)

.....
(individual)

Table 2
SAND TEST FIGURES AND FOUNDRY CONDITIONS FOR SAND SAMPLES SUBMITTED

Sample No.	Moisture		Permeability Pre. A.F. No.	Green compression		Deformation in 100 lb. Specimen	Dry compression		Type** Mold- ing	Riddle No.	Method of Ram	Mold Protection	Casting finish	Wt. of Casting	Avg. Temperature of Thick- ness Metal Vented	Sides of Flask
	Per- cent	Temp.		Shear, Sq. In. Lib.	Spec. in 1000 Sq. In. cent		Real- sion, Lib. Sq. In. cent	Sub- sidence, Lib. Sq. In. cent								
Aluminum Sands																
1	7.3	3.0	2.50	8.9	0.0157	141	48.2	27.5	Nat. Floor Shovel	6	Squeezer Hand	None	Smooth	2 oz.-5 lbs.	1300 to 1500	No
2	8.3	3.0	2.30	8.7	0.0147	128	83.0	21.1	Nat. Sym. Aerator	.....	Squeezer Jolt	None	Smooth	5-100 lbs.	1300 to 1500	No
3	6.8	5.0	1.88	6.5	0.0109	71	15.2	21.1	Nat. Floor Shovel	6	Squeezer Jolt	None	Very Smooth	1/2-5 lbs.	1300 to 1520	No
4	6.4	3.0	2.27	8.8	0.0083	73	40.3	24.9	Nat. Floor Cutter	10 & 16	Squeezer Hand	None	Smooth	1/4-10 lbs.	1320 to 1400	Yes
5	8.0	13.0	1.29	5.2	0.020	104	22.0	10.2	Nat. Floor Aerator	6	Hand	None	Med.	5-200 lbs.	1-1 1/2 to 1400	No
6	8.4	6.2	1.70	6.8	0.024	183	16.2	15.2	Nat. Floor Aerator	6	Hand	None	Smooth	6 1/2 lbs.	.....	No
Brass Sands																
5	8.0	13.0	1.29	5.2	.....	.....	22.0	10.2	Nat. Floor Aerator	6	Hand	None	Med.	5-200 lbs.	1-1 1/2 to 2100	No
7	6.8	18.5	1.5	5.3	0.0079	42	23.5	10.2	Nat. Floor Aerator	6	Rapid Squeezer	None	Med.	6 oz.-3 lbs.	2200 to 2650	No
8	7.3	13.0	1.95	6.9	0.0100	69	67.8	14.5	Nat. Sym. Aerator	4	Squeezer	None	Smooth	1/2 oz.-5 lbs.	1350 to 2250	No
9	6.0	14.5	1.90	7.7	0.0084	65	54.5	12.3	Nat. Floor Aerator	4	Jolt Hand	None	Smooth	10-75 lbs.	.....	No

Table 2—Continued

10	5.8	15.0	1.92	7.9	0.0122	96	50.3	12.4	Nat. Floor	6	Squeezer Jolt	None	Smooth	3 oz.-7 lbs.	¼	2250 to 2300
11	6.3	12.0	2.0	7.9	0.0143	113	62.8	13.0	Nat. Floor	6	Squeezer Jolt Hand	Flour	Smooth	1 oz.-300 lbs.	¼	2120 No
12	7.7	23.0	1.18	3.9	0.0047	18	20.8	10.4	Nat. Floor	8 & 6 Shovel & Riddle Muller	Squeezer Jolt	None	Med.	2-10 lbs.	¼	2150 No
13	6.9	13.5	1.85	6.7	0.0109	73	50.0	11.6	Nat. Floor	8	Squeezer Jolt	Flour	Smooth	5 oz.-55 lbs.	¾	2250 No
14	7.2	19.0	1.75	6.2	0.0139	86	68.3	12.9	Nat. Floor	8	Squeezer Jolt	Flour	Med.	45-200 lbs.	½	2180 No
<i>Bronze Sands</i>																
4	6.4	3.0	2.27	8.8	0.0083	73	40.3	24.9	Nat. Floor	10 & 16 Sand Cutter	Squeezer Hand	None	Smooth	¼-10 lbs.	¾	2200 Yes
15	7.2	9.0	2.10	7.7	0.0102	79	37.3	14.3	Nat. Floor	4	Squeezer Jolt Hand	Plumbago	Med.	1-500 lbs.	1½	2150 No
16	6.8	13.6	1.32	5.7	0.022	125	18.7	9.1	Nat. Floor	6	Hand	Flour & Plumbago	Med.	5-1600 lbs.	1	2200 No
<i>Copper-Nickel Sands</i>																
17	3.1	97	1.43	5.1	0.0072	37	34.3	3.4	Syn. Floor	4	Jolt Hand	Silica Flour	Smooth	No Limit	1	2830 No
18	6.2	37	1.27	5.0	0.0083	41	36.5	9.5	Nat. Floor	4	Squeezer Jolt Hand	Mica	Med.	10 lbs.	¼	2800 No
<i>Copper Sands</i>																
19	6.2	290	0.7	2.7	0.0025	7	48.0	11.7	Cement Floor	6	Hand	Bone Ash	Med.	2736 lbs.	1½	2000 Yes
20	6.2	310	0.5	1.7	0.0015	3	40.5	11.3	Cement Floor	6	Hand	Bone Ash	Med.	2736 lbs.	1½	2000 Yes

* Nat.—Natural Bonded Sand; Syn.—Synthetic Bonded Sand.

** Floor—Floor; Syn.—System.

4. All sand samples were received in sealed containers and were conditioned as used in the foundry. The samples Nos. 19 and 20 are an exception in that they were received in a dry state due to the nature of bond. Proper moisture was added in our laboratory. The sand samples were tested as received for moisture, permeability, green strength, deformation, dry strength, clay content and fineness.

5. The equipment and procedure for testing the sand samples were in accordance with A.F.A. Specifications. The equipment used in the various tests was as follows: Moisture Test, moisture teller and balance; Permeability Test, sand rammer and permeability meter; Strength—Deformation Test, sand strength machine, hand operated, with deformation accessory; Fineness Test, drying oven, rapid sand washer, clay washer, testing sieves and sifter.

6. The sand test figures of the sands tested are shown in Table 2, with the exception of the fineness test data which is shown in Table 3. The test data is shown in five groupings, namely, aluminum, brass, bronze, copper-nickel and copper sands.

SUMMARY OF SAND AND FOUNDRY CONDITIONS.

7. The general sand and foundry conditions prevailing in these thirteen foundries is summarized in Table 4. A number of the outstanding facts as found in this table are worthy of brief discussions.

Kind of Sand.

8. There are three distinct classes of molding sands in use. They are natural, synthetic and cemented sands. The natural molding sand, at present, holds almost exclusively the fine grained molding sand field where the permeability is 25 or less. This survey shows that seventeen samples were natural molding sand, one was synthetically bonded, and two were cement bonded.

Method of Molding.

9. The continuous sand system is not used as much in non-ferrous foundries as it is in ferrous foundries. Eighteen sand samples were used on floor molding, while two were used as sand systems. Molding machines are mostly used. Only five samples were submitted where hand ramming was used.

Table 3

FINENESS TEST DATA AND A. F. A. FINENESS NUMBERS OF
SAND SAMPLES SUBMITTED

Sample No.	Percent Material Remaining on Respective Sieves											A.F.A.	
	Sieve No. 12	Sieve No. 20	Sieve No. 30	Sieve No. 40	Sieve No. 50	Sieve No. 70	Sieve No. 100	Sieve No. 140	Sieve No. 200	Sieve No. 270	Pan	Fineness No.	Percent Fines*
<i>Aluminum Sands</i>													
1	0.0	0.2	0.4	0.6	2.6	3.9	2.5	4.3	5.9	7.7	44.0	228.5	57.6
2	0.0	0.1	0.2	1.1	3.6	6.8	3.6	5.2	7.0	8.8	42.5	212.5	58.3
3	0.0	0.2	0.2	0.5	0.9	2.0	2.4	7.1	10.3	12.9	42.4	225.5	65.6
4	0.0	0.1	0.1	0.4	0.6	1.2	1.1	3.8	5.5	9.1	53.2	254.0	67.8
5	0.3	0.5	0.7	1.7	4.1	13.4	8.9	11.8	13.5	11.7	22.9	154.5	48.1
6	1.4	0.6	0.4	1.2	2.8	9.6	6.7	9.3	10.3	9.8	31.7	178.7	51.8
<i>Brass Sands</i>													
5	0.3	0.5	0.7	1.7	4.1	13.4	8.9	11.8	13.5	11.7	22.9	154.5	48.1
7	2.0	2.4	2.0	1.9	1.6	8.5	6.0	4.0	13.6	28.5	19.3	165.5	61.4
8	0.1	0.4	0.4	0.9	3.5	9.5	8.2	14.3	12.6	12.3	23.3	162.2	48.2
9	0.3	0.5	0.4	1.3	4.2	10.7	8.6	14.3	14.0	11.1	22.3	155.8	47.4
10	0.2	0.3	0.3	1.4	4.8	11.9	9.2	13.1	13.6	10.9	21.9	153.5	46.4
11	0.0	0.5	0.4	0.6	2.7	9.8	8.6	11.6	11.2	11.7	29.9	175.7	52.8
12	0.1	0.3	0.7	1.5	3.2	7.8	10.2	20.7	19.1	12.3	14.7	142.2	45.1
13	0.0	0.0	0.4	0.8	4.8	15.6	10.1	9.4	9.6	10.9	26.8	160.9	47.3
14	0.0	0.0	0.4	0.2	6.3	1.5	31.2	9.5	9.0	9.6	17.6	137.5	36.2
<i>Bronze Sands</i>													
4	0.0	0.1	0.1	0.4	0.6	1.2	1.1	3.8	5.5	9.1	53.2	254.0	67.8
15	0.9	3.0	2.6	4.8	6.7	9.5	5.8	7.3	8.4	10.0	26.7	155.2	45.1
16	0.3	0.9	0.7	2.3	5.9	12.7	8.4	12.7	12.8	11.5	22.7	151.2	47.0
<i>Copper-Nickel Sands</i>													
17	0.0	0.0	0.6	1.8	7.3	39.1	29.9	16.5	1.0	0.2	0.2	65.1	1.4
18	0.0	0.7	1.3	0.6	2.3	6.4	7.7	27.6	27.5	9.9	7.5	130.0	44.9
<i>Copper Sands</i>													
19	0.0	3.4	18.5	30.7	21.2	10.0	1.7	0.7	0.2	0.2	1.7	39.0	2.1
20	0.0	3.5	20.2	31.3	20.3	9.2	1.6	0.5	0.2	0.2	1.7	38.2	2.1

*Material remaining on 200, 270 and pan mesh in Fineness Test.

Table 4

GENERAL SAND AND FOUNDRY CONDITIONS.

Condition	Number Reported
Natural Sand.....	17
Synthetic Sand.....	1
Cement Sand.....	2
Sand used on Floor.....	18
Sand used in System.....	2
Sand prepared with Shovel & Riddle.....	6
Sand prepared with Aerator.....	9
Sand prepared with Sand Cutter.....	2
Sand prepared with Muller.....	3
Flask Vented.....	3
Flask not vented.....	17
Mold Dust.....	9
Pyrometer Temperature Readings.....	19
Smooth Finish.....	11
Medium Finish.....	9
Rough Finish.....	0

(Table 4 continued on Page 88)

Table 4—Continued

Samples with permeability less than 10:	
Aluminum	5
Brass and Bronze.....	2
Samples with permeability 10 to 20:	
Aluminum	1
Brass and Bronze.....	10
Samples with green compression strength less than 7.5 lb. per sq. in.:	
Aluminum	3
Brass and Bronze.....	7
Samples with green compression strength more than 7.5 lb. per sq. in.:	
Aluminum	3
Brass and Bronze.....	5
Samples with deformation less than 0.010 in.:	
Aluminum	1
Brass and Bronze.....	4
Samples with deformation more than 0.010 in.:	
Aluminum	5
Brass and Bronze.....	8
Samples with dry compression strength below 25 lb. per sq. in.:	
Aluminum	3
Brass and Bronze.....	4
Samples with dry compression strength greater than 25 lb. per sq. in.:	
Aluminum	3
Brass and Bronze.....	8
Samples with majority of grains on pan:	
Aluminum	6
Brass and Bronze.....	9
Samples with majority of grains not on pan:	
Aluminum	0
Brass and Bronze.....	3

Sand Preparation.

10. The areator type of sand preparation was used to prepare nine of the sands. Two sands were prepared with a sand cutter. The muller was used to prepare three sands. The shovel-riddle method was used in six instances.

11. Non-ferrous foundries, where the floor method of molding is practised, have a problem to secure a uniformly tempered sand, since the sand is frequently used over after each heat and quickly thrown in a large pile with insufficient attention paid to obtaining a high quality sand.

Flask Equipment.

12. Venting the sides of flasks to improve venting of molds is not as essential in non-ferrous foundry practice as it is in ferrous foundry practice. Three sand samples were submitted that were used in vented flasks while seventeen samples were used in flasks not vented.

Mold Dust Facing.

13. Non-Ferrous metals are poured at temperatures below the sintering point of the sand. This is not the case in highly alloyed non-ferrous castings or ferrous castings where mold dust or wash is frequently used. It is interesting, however, to note that nine of the sands were used with mold dust while eleven were used unprotected.

Casting Finish.

14. The nature of the casting finish is receiving increasing attention. Eleven of the sand samples were reported as producing smooth finish, while nine samples were reported to give medium finish.

15. Referring to Fig. 1, the relation between casting finish

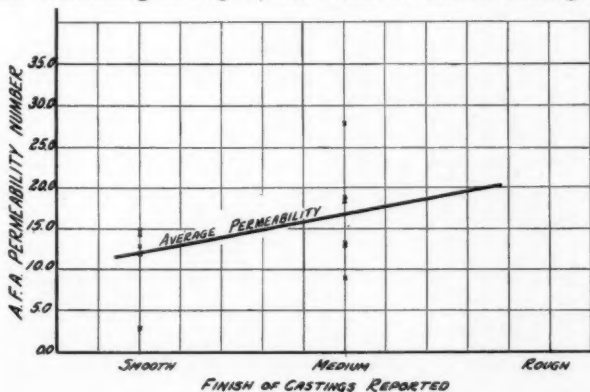


FIG. 1.—RELATION BETWEEN PERMEABILITY AND CASTING SURFACE FINISH ON BRASS AND BRONZE CASTINGS.

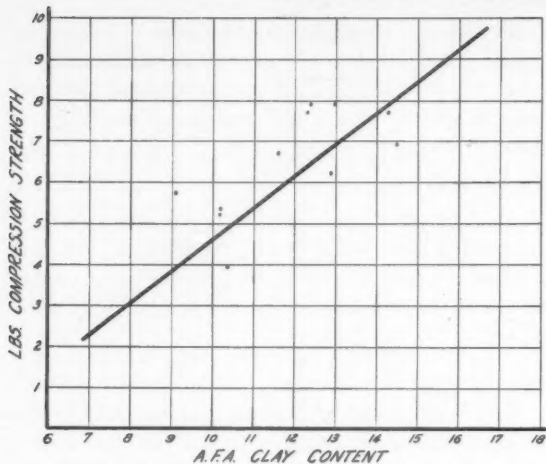


FIG. 2—RELATION BETWEEN GREEN COMPRESSION STRENGTH AND A.F.A. CLAY SUBSTANCE IN NON-FERROUS MOLDING SANDS.

and permeability of the sand may be noticed for brass and bronze castings. Smooth finished castings were produced with an average permeability of 12.0. Medium finished castings were produced with an average permeability of 16.8.

SUMMARY OF SAND PROPERTIES.

Green Strength.

16. Many natural, fine molding sands have a tendency toward a low green strength. The result is that the heap sand will become low in green strength unless a generous amount of new sand is used. A fairly ideal green compression strength for a general line of castings is 7.5 lb. per sq. in. Three of the aluminum sands and seven of the brass and bronze sands possessed a green compression strength of less than that figure. Three of the aluminum sands and five of the brass and bronze sands possessed a green compression more than 7.5 lb. per sq. in.

17. The relation between the A.F.A. clay substance and green compression strength is shown in Fig. 2. Fig. 2 is identical to the relation found for the malleable iron molding sands. Sands used for aluminum castings are not plotted in Fig. 2 due to the fact that the clay substances as obtained by test were very high.

Deformation.

18. The deformation of a sand is the measure of its plasticity.

A sand low in plasticity will be short or brittle and low in deformation. Using 0.010 in. per in. deformation as a conservative deformation value, it is found that only one aluminum sand has a deformation below 0.010 in. per in. The brass and bronze sands show four samples less than that figure and six samples above 0.010 in. per in.

Dry Strength.

19. The dry strength of non-ferrous sand samples varied from 15.2 to 83 lb. per sq. in. Dry strength values below 25 lb. per sq. in. are not recommended for brasses, but may be used for aluminum sands. For copper and nickel castings, a dry strength of 40 lb. per sq. in. or better is advantageous.

20. Half of the aluminum sands showed a dry strength less than 25 lb. per sq. in. Of the brass and bronze sands, four showed less than that figure while eight showed greater dry strength than 25 lb. per sq. in.

Moisture.

21. The moisture content of the sand samples shows a wide variation due principally to the wide variation in fines and green strength. The fines consist of the very small silica sand grains which are retained on the 200, 270 sieves and pan. This fines material consumes a considerable quantity of moisture. Thus as fines increase, more moisture is required to temper the sand.

22. There is a second factor in determining the quantity of moisture required to temper a sand. It is better to work a high green strength sand at a low moisture content to reduce the effect of the large amount of clay substance. Conversely, a sand low in green strength is worked high in moisture content to obtain the maximum plasticity of the clay substance.

23. This relation is shown graphically in Fig. 3 where a line is plotted which may be used to determine the best theoretical working moisture content of natural molding sand, providing the percentage of fines and green compression strength is known. The dots on graph show where moisture content of samples submitted fall on the graph. This graph is useful for gray iron, malleable and non-ferrous natural sands.

24. The graph is used as explained in solving the following example: The natural molding sand used in a foundry possesses a green compression strength of 7.5 lb. per sq. in. and 50 per cent

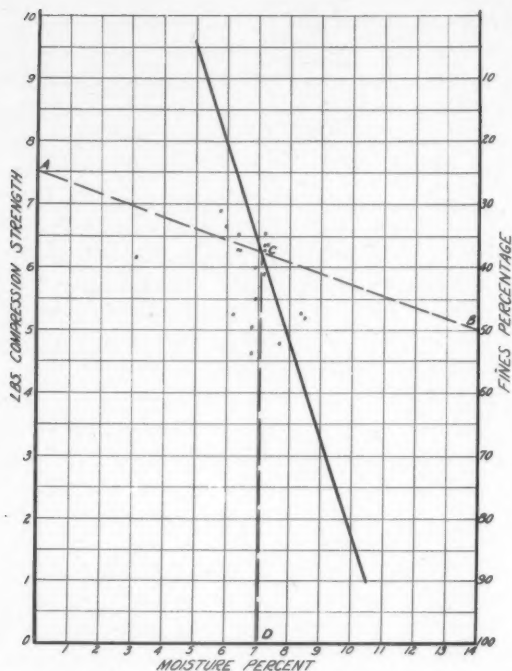


FIG. 3—CHART SHOWING THE RELATION BETWEEN STRENGTH, FINES AND MOISTURE CONTENT OF NON-FERROUS SANDS.

finer. Draw a line from point A to point B respectively 7.5 and 50. Where this line AB intersects the graph at C, draw a line straight down to moisture of 7.1 per cent.

25. The Formula H may be used to calculate this moisture percentage in place of using the graph Fig. 3, as follows:

Formula H

$$\text{Moisture} = \frac{\text{Fines}}{20} + 6.7 - \frac{\text{Compression}}{5}$$

26. The strength—fines—moisture graph and formula H will, in part, answer the frequent inquiry as to the proper amount of moisture in a sand. It is of interest to know that the graph, Fig. 3, is the same graph that was formulated for malleable iron sands. This same graph is now found useful for non-ferrous sands. A comparison of actual moisture percentages of sand samples as sub-

mitted and moisture percentages as obtained from the graph, Fig. 3 or by Formula *H*, is shown in Table 5.

Permeability.

27. The permeability of the non-ferrous sand samples ranged from 3 to 310. This range was used to produce castings which weighed from a few ounces to 2,736 lbs. of the usual non-ferrous metals and special alloyed metals.

28. The permeability of sands used for aluminum castings ranged from 3 to 13.0 showing that foundrymen took advantage of the quick setting and low pouring temperatures of aluminum which makes it permissible to use a low permeability sand to secure best possible casting finish.

Table 5
COMPARISON BETWEEN SHOP MOISTURE CONTENT AND MOISTURE
CONTENT OBTAINED FROM STRENGTH-FINES-MOISTURE
GRAPH, FIG. 2

Sample Numbers	Shop Moisture Content	Graph Moisture Content	Difference
ALUMINUM SANDS			
1	7.3	6.8	— .05
2	8.3	6.9	—1.4
3	6.8	8.0	+1.2
4	6.4	7.2	+0.8
5	8.0	8.8	+0.8
6	8.4	7.4	—1.0
BRASS SANDS			
5	8.0	7.8	—0.2
7	6.8	8.2	+1.4
8	7.3	7.1	—0.2
9	6.0	6.9	+0.9
10	5.8	6.8	+1.0
11	6.3	6.9	+0.6
12	7.7	8.0	+0.3
13	6.9	7.2	+0.3
14	7.2	7.1	—0.1
BRONZE SANDS			
4	6.4	7.2	+0.8
15	7.2	6.9	—0.3
16	6.8	7.6	+0.8
COPPER-NICKEL SANDS			
18	6.2	7.7	+1.5

29. The permeability of the brass sand shows a range from 13 to 28. There are foundrymen who are using higher permeability such as 35 for brass castings that are cored.

30. The samples of sand which were used for bronze castings as reported showed a permeability range of from 3 to 13.6. This permeability range is considered low for bronze castings that are cored where permeabilities of 35 to 48 are advantageous.

31. The two sand samples submitted for copper-nickel alloys possessed 35 and 97 permeability. The 35 permeability sand was used for castings weighing up to 10 lbs.; while the 97 permeability sand was used for the heavy castings with no limit on weight. For the heavy copper-nickel castings, a molding sand and practice similar to steel foundry practice is followed.

32. It is of particular note that cement bonded sands have found use in the non-ferrous foundry. The samples Nos. 19 and 20 were such sands with permeabilities of 290 to 310 for large copper castings.

33. The permeability of a molding sand is largely controlled by the clay substance content and grain fineness. The grain distribution is also a controlling factor. Using the green compression strength as a measure of the actual clay substance and grain fineness, a graph as shown in Fig. 4 may be used to determine the probable permeability. This is the same graph as used for malleable iron sand and it is of interest to note that this graph is useful for non-ferrous sand. The dots shown in Fig. 4 represent non-ferrous sands. All points do not fall near the curve since the curve is for a 7.5 lb. per sq. in. strength sand. When the strength is higher, the permeability of the sand is reduced; and when strength is lowered, the permeability is increased.

34. The permeability of a sand may be fairly closely calculated by Formula C' when the green strength and grain fineness are known.

Formula C'

$$\text{Green Permeability} = \frac{3.75}{\text{compression}} S \left(\frac{714}{3 + M} \right)^2$$

Where:

$S = 1.0$ for rounded sand grains

$M = \text{A.F.A. Fineness Number}$

Fineness.

35. The fineness test of the samples submitted shows that non-ferrous sands have a wide grain distribution. This is a condi-

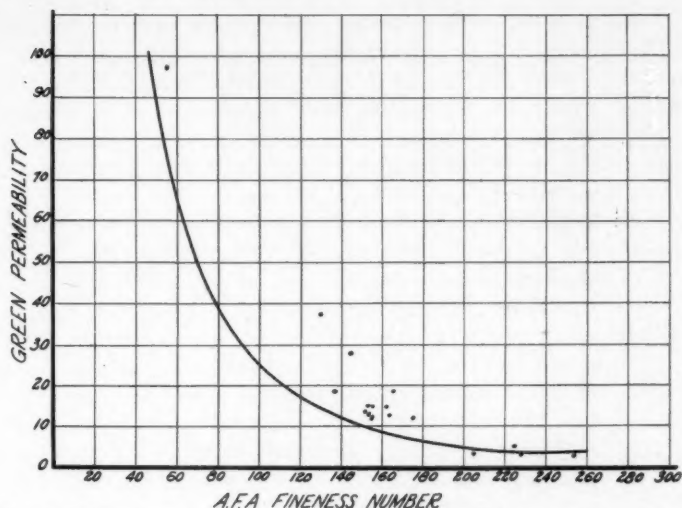


FIG. 4—RELATION BETWEEN PERMEABILITY AND A.F.A. FINENESS NUMBER WHEN GREEN COMPRESSION STRENGTH IS 7.5 LB. PER SQ. IN.

tion usually avoided in molding sands for ferrous castings. Another outstanding point is that the majority of the samples submitted contained pan material in large percentages. All of the aluminum sands had a majority of sand grains on the pan. For brass and bronze sands, nine showed largest percentage on pan and only three showed majority of grains other than pan.

36. The A.F.A. fineness number of aluminum sands ranged from 154 to 254; and from 137 to 175 for brass sands.

CONCLUSIONS

37. The conclusions reached from the data of this investigation are not conclusive for all molding sand conditions found in non-ferrous foundries; but it is felt that the samples tested were representative to a sufficient extent to render the conclusions indicative and of some practical value.

1. Natural sand is used exclusively for small aluminum and brass castings.
2. Mechanical equipment is used quite extensively for the preparation of sand in the non-ferrous foundries.
3. Few non-ferrous foundries vent the flask equipment to aid venting of molds.

4. Nine out of the twenty sand samples were used with a mold dust to improve the finish of castings.
5. Eleven of the sand samples produced smooth finish, and nine produced medium finish according to data furnished with sand samples.
6. All except one sand used for aluminum castings possessed a permeability less than 10.
7. Ten of the twelve sand samples for brass and bronze castings possessed a permeability between 10 and 20.
8. A green compression strength of 7.5 lb. per sq. in. is substantially the average strength of non-ferrous molding sands.
9. Most of the aluminum, brass and bronze molding sands possessed a deformation greater than 0.010 in. per in.
10. The dry strength of non-ferrous sands varies considerably.
11. Pan material is very prominent in all of the aluminum sand samples submitted. In brass and bronze sands, nine out of twelve samples contained a majority of sand grains on pan.
12. The permeability of a molding sand may be calculated fairly closely by Formula C'.

$$\text{Permeability} = \frac{3.5}{\text{compression}} S \left(\frac{714}{M + 3} \right)^2$$

Where $S = 1.0$ for non-ferrous sands.

13. The approximate moisture required to temper a molding sand may be calculated by Formula H.

$$\text{Moisture} = \frac{\text{Fines}}{20} + 6.7 - \frac{\text{compression}}{5}$$

Report of Steel Division Committee on Test Coupons

*To Members of the Steel Division,
American Foundrymen's Association:*

This is the second and continuing report by this committee. The first report appeared in the 1936 Transactions* of the A.F.A.

Actual soundness of the casting is the most important requirement in securing a good test result from any specimen. A specimen cut from certain sections so designed as to make it commercially unfeasible to prevent axial shrinkage should be appraised with the knowledge that the lower density occurs at a point that is, for all practical purposes, the neutral axis of the member and has very little effect on the serviceability of the casting. C. E. Sims brought out this point during the 1936 Detroit Convention. However, for those castings subjected to pressure and corrosion, the physics involved in solidification legislate against this center section being regarded merely as an area of low density. It is a microscopic void connected to the outside by one or more openings.

As an example of Sims' point, a 1¾ in. thick section of a low alloy steel was cast in both a vertical and horizontal plane (see Figs. 1 and 2) with the following results:

	Vertical Cast			Horizontal Cast		
	Center	Inside	Outside	Center	Top	Bottom
Tensile Strength, lb. per sq. in.	90,750	89,500	89,000	91,500	90,800	89,300
Yield Point, lb. per sq. in.	65,300	61,300	60,650	64,050	63,050	61,350
Elongation, per cent	11.0	25.5	26.0	17.0	24.5	27.0
Reduction of Area, per cent.	16.6	46.5	47.7	31.2	41.5	49.1

Polishing and etching of these sections did not reveal any shrinkage to the eye, but under a glass it was revealed.

Certain elements tend to aggravate the poor physical properties in the center of a relatively heavy section, due either to segregation or the effect of the element on inclusion precipitation. An example of the latter case lies in the use of aluminum. When the steel solidifies rapidly, in either thin sections or heavy sections faced with an external chill, the physical properties are quite good even when the steel has been treated with a generous amount of aluminum. With the same amount of aluminum, the physical

* "Report of Steel Division Committee on Test Coupons," Trans. A.F.A., vol. 44, pp. 133-138, (1936).

NOTE: This report was presented before the Steel Division Session of the 41st Annual Convention, Milwaukee, Wis., May 4, 1937.

properties in the heavy section are not nearly as good. The same applies to some of the alloying elements that tend to segregate.

Specifications for steel castings usually cover allowable minimum values to be met for acceptance as to physical properties. In only a few specifications is the size of the test piece mentioned. We believe that when specifications are drawn up, the required physical properties are based on actual results obtained over a period of time by a group of foundries and that these results are obtained from relatively small test coupons cast as an integral part of, or gated to, the casting. The physical properties thereby obtained are only a comparative measure of the analysis and its subsequent annealing, rather than an actual measure of the properties to be found in any of the various cross sections of the casting itself, or in test specimens taken from coupons of various cross section.

To show the effect of size on a cast test coupon and to compare the physical properties obtained in a test coupon with those prop-

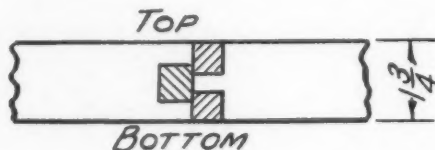


FIG. 1

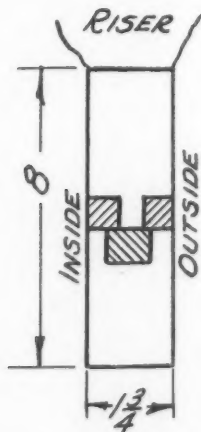


FIG. 2

Table 1
Effect of Size on Test Coupon and Comparison of Physical Properties Obtained in Test
Coupon with Those Obtained in Casting

Heat No.	Cast Test Piece Per Fig.	Analysis			Anneal	Location of Test	Physical Properties			
		C.	Mn.	P.	S.		Tensile lb./sq. in.	Yield Point lb./sq. in.	Elong. in 2 in. Per Cent	Red. of Area Per Cent
179	Fig. 3	0.29	0.60	0.028	0.037	0.32	70,000	38,500	20.0	25.13
							68,500	36,500	21.0	24.08
							69,000	37,500	21.5	25.13
							66,000	37,500	13.0	19.52
							72,500	42,000	26.5	35.10
204	Fig. 6	0.23	0.66	0.030	0.038	0.30	65,000	37,000	35.0	49.18
	Fig. 3						65,000	34,000	35.0	49.18
							64,000	34,000	32.0	50.00
							64,500	34,000	32.5	51.12
							65,000	33,000	31.0	51.12
							65,000	37,500	32.5	50.57
							66,000	35,000	33.5	52.77
212	Fig. 6	0.29	0.74	0.032	0.034	0.33	72,000	38,000	19.5	26.47
	Fig. 3						73,000	39,000	22.0	29.83
							74,000	41,000	24.0	30.50
	Fig. 6						71,000	37,000	23.5	33.10
644	Fig. 3	0.23	0.68	0.028	0.030	0.34	72,000	37,000	25.0	34.08
	Fig. 4						65,000	35,000	23.0	33.75
							67,500	37,500	21.0	30.50
							68,000	37,000	23.0	33.75
							65,000	37,000	33.0	54.67
							68,000	42,000	32.0	52.77
							66,500	37,000	30.0	44.85
205	Fig. 6	0.27	0.75	0.036	0.043	0.37	68,500	39,000	16.0	17.02
	Fig. 4						68,000	39,000	13.5	17.02
							70,000	40,000	18.0	20.59
							72,000	43,000	24.0	34.08
							72,000	43,000	25.0	32.45
							72,000	41,000	24.5	31.48
251	Fig. 6	0.22	0.65	0.028	0.041	0.34	61,500	34,000	16.5	23.08
	Fig. 4						62,000	35,000	15.0	18.80
							64,000	35,000	19.0	23.08
							63,000	37,000	27.0	38.50
							65,000	38,000	26.5	40.05
							65,000	40,000	27.5	38.81
254	Fig. 6	0.26	0.80	0.025	0.035	0.30	64,000	37,000	12.0	17.02
	Fig. 4						65,000	37,500	13.0	18.80
							66,000	37,500	13.5	18.80
							70,000	39,000	25.0	36.30
							70,000	37,500	26.5	37.36
							72,500	42,500	26.5	37.26
212	Fig. 6	0.27	0.70	0.026	0.034	0.32	69,000	37,500	25.5	38.19
	Fig. 5						70,000	37,000	26.0	39.12
							69,000	37,000	21.5	26.47
							70,000	37,000	21.0	26.47
							70,000	35,500	26.5	42.47

* 17 hrs. to bring to 1675°F. Held at 1675°F. for 10 hrs. and furnace cooled.

erties obtained in a casting, Table 1 has been compiled. Reference to it will show that with a given annealing, the size has a great effect on physical properties. In some cases, the desired ductility can be developed by a longer anneal, but usually it requires a double anneal. Then there are instances where this has failed to produce the desired ductility. Coupons cut from a section of a heavy casting have been found to have low ductility, even though the test coupons showed excellent results. The heavier the casting, the lower the ductility will be at the center of the heavy section,

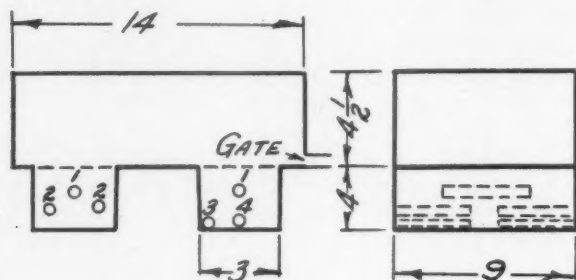


FIG. 3

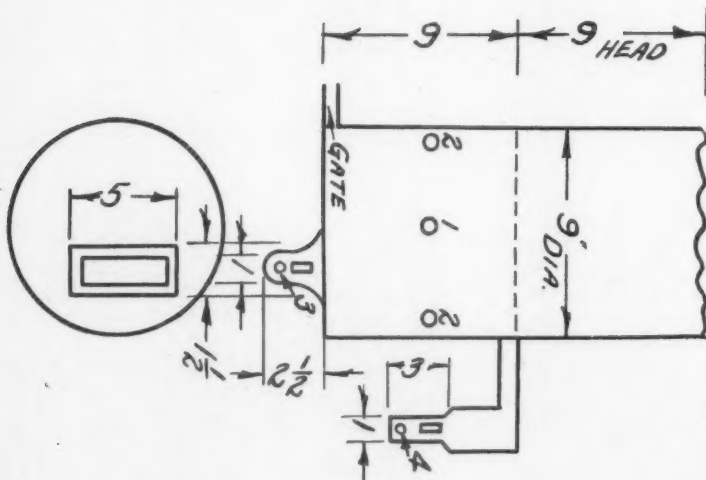


FIG. 4

although the tensile strength and yield point will be comparable to those obtained on the cast test coupon.

In the compiling of those results, blocks used shown in Figs. 3 and 5, are a heavy design of the conventional keel-block type and illustrate the effect of size when compared to block shown in Fig. 6. It will be noted in Table 1 that, with greatly increased annealing time, better results are obtained with the heavy block shown in Fig. 3. It will also be noted that the physical properties of specimens taken from the block shown in Fig. 5 materially fall off in ductility as they approach the head, or heavier section of the keel block.

To show the effects of mass on properties in a casting and the

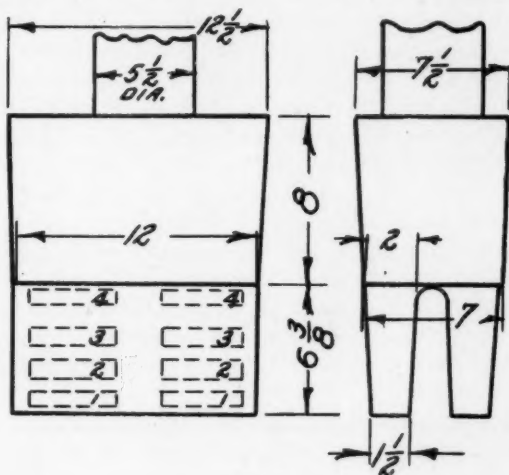


FIG. 5

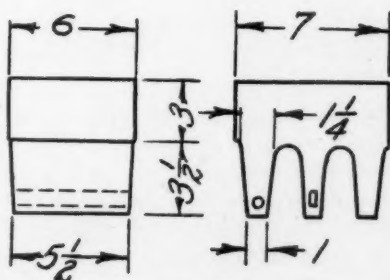


FIG. 6

block, Fig. 6, the castings shown in Fig. 4 were made and tests cut out as shown. Examination of these results in Table 1 indicate that bars cut from the 9-in. section are low in ductility whereas better results are shown to exist in the "cast on" and "gated" test pieces.

The tendency in some quarters to set up, arbitrarily, their own size test coupon, based on the wall thickness of the casting and then ask that the standard specification physical properties be met, should be discouraged for the reason that it works a distinct hardship on the foundry in that standard physical properties are based on properties obtained on a size coupon different from that called for in the design of the casting.

Some interesting results were obtained on a manganese-vanadium alloy steel and a manganese-molybdenum alloy steel, used in making castings running from 11 to 12 tons in weight.

Test coupons 2 x 4 x 48-in., 8 x 8 x 14-in., and 15 x 15 x 15-in. were cast from each heat and were annealed with the castings. These coupons were tested at the surface, midway between surface and center, and at center. Hollow drilled test specimens taken from 6-in. section of flange of casting, check the coupon results. Results are shown in Table 2.

Manganese-vanadium steel casting was treated as follows: Annealed at 1560 to 1600° F. (850 to 870° C.) for 16 hours and furnace cooled. After rough machining, annealed at 1560° F. (850° C.) for six hours, and furnace cooled to 390° F. (200° C.), reheated to 1380° F. (750° C.) for 10 hours and furnace cooled to 210° F. (100° C.).

Manganese-molybdenum steel casting was treated as follows: Annealed at 1560 to 1600° F. (850 to 870° C.) for 16 hours and furnace cooled. Reheated to 1740° F. (950° C.) for 16 hours and furnace cooled. After rough machining, annealed at 1560° F. (850° C.) for six hours and furnace cooled to 390° F. (200° C.). Reheated to 1380° F. (750° C.) for 10 hours and furnace cooled to 210° F. (100° C.).

It should be said in passing, that present day heat treatment would materially improve the physical properties shown in Table 2 for manganese-molybdenum steel.

There appears to be little difference in physical properties of carbon cast steel coupons whether the coupons are cast as an integral part of, or gated to, the casting. However, the view is held by some that these differences increase as the steel changes from

Table 2

EFFECT OF SECTION SIZE ON PROPERTIES OF TWO ALLOY STEEL CASTINGS.

Chemical Analysis

	C.	Mn.	Si.	P.	S.	Va.	Mo.
Manganese Vanadium	0.33	0.97	0.29	0.044	0.028	0.26	....
Manganese—Molybdenum	0.33	0.99	0.31	0.034	0.023	....	0.30

Physical Properties of Test Coupons after Final Heat Treatment

Compo- sition	Test Bar 512 P-in.	Location from which Test Bar taken	Tensile Strength lb./sq. in.	Yield Point lb./sq. in.	Elastic Limit lb./sq. in.	Elong. in 2 in. Per Cent	Red. Area Per Cent	B.H. No.
Mn-Va	2 x 4 x 48		72,000	44,700	41,000	17.5*	23.5	145
Mn-Va	"		74,000	45,900	45,000	32.0	51.2	
Mn-Mo	"		72,500	36,690	34,000	33.0	56.0	145
Mn-Mo	"		69,700	33,700	32,000	15.0†	19.5	
Mn-Va	8 x 8 x 14	Skin	75,000	44,400	38,000	33.0	59.9	135
Mn-Va	"	Midway	72,300	41,400	38,000	32.0	57.0	135
Mn-Va	"	Center	70,800	38,700	37,000	33.0	56.0	135
Mn-Mo	"	Skin	76,600	34,200	32,000	30.0	49.2	145
Mn-Mo	"	Midway	72,900	33,900	32,000	29.0	46.4	145
Mn-Mo	"	Center	71,500	31,900	29,000	29.0	51.3	135
Mn-Va	15 x 15 x 15	Skin	75,500	46,400	44,000	32.5	60.0	146
Mn-Va	"	Midway	70,600	38,400	37,000	28.5	49.3	136
Mn-Va	"	Center	69,000	48,000	47,000	32.0	54.0	134
Mn-Mo	"	Skin	75,400	34,400	32,000	31.5	51.2	141
Mn-Mo	"	Midway	72,500	31,200	29,900	32.0	48.8	138
Mn-Mo	"	Center	72,000	32,400	29,000	22.0	25.0	149

* 45° Fracture, slightly crystalline.

† Flawed specimen and crystalline fracture.

Results from Hollow Drilled Specimens Taken from Approximately 6-in Sections of Flange of Shells Following Final Heat Treatment

Compo- sition	Tensile Strength lb./sq. in.	Yield Point lb./sq. in.	Elastic Limit lb./sq. in.	Elong. in 2 in. Per Cent	Red. Area Per Cent	Brinell No.
Mn-Va	71,800	40,200	40,000	24.0	50.1	143
Mn-Mo	71,400	35,600	29,000	26.0	50.0	141

Results Obtained on 2x4x48-in. Test Bars After First Anneal

Compo- sition	Tensile Strength lb./sq. in.	Yield Point lb./sq. in.	Elastic Limit lb./sq. in.	Elong. in 2 in. Per Cent	Red. Area Per Cent	Brinell No.
Va	81,800	47,300	44,700	24.0*	34.4	161
	80,100	49,100	47,000	28.5	43.4	
Mo	76,000	35,900	34,000	25.0	31.5	154
	78,500	36,500	35,000	13.0	20.0	

* 40° Fracture.

that of a plain carbon grade to the complex medium alloy grades such as manganese-chromium-nickel-molybdenum steel.

It is believed that in making comparisons between different size coupons, location of coupons (cast integrally, gated to casting, or cast separately), or of tests cut from the casting section itself), such coupons should be viewed with the following conditions in mind:

1. Density of the metal under a microscope, as an indication of the efficiency of the risers and the ability of the section to be fed from the risers.
2. Effect of mass, particularly upon segregation of certain elements.
3. Thermal effects during heat treatment, particularly where heavy and light sections are involved.

During the past year a very worthwhile contribution to this subject was presented in a paper at the Annual Meeting of the American Society of Mechanical Engineers in December 1936. The paper was titled, "*Physical-Property Uniformity in Valve-Body Steel Castings*," by A. E. White, C. L. Clark, and Sabin Crocker. The summary given in this paper is as follows:

This paper gives the results of tests made on carbon-molybdenum cast-steel valve bodies with the welding ends to determine (1) if the material in the welding end is sound; (2) if the properties in these welding ends differ from those in separately or integrally cast lugs; and (3) if the physical properties throughout the entire valve bodies are reasonably uniform.

The results showed that for valve-body castings of the type examined, it is possible to obtain: (1) sound material in the welding ends; (2) properties from welding ends commensurate with those from conventional bars; and (3) castings with reasonably uniform physical properties. These conclusions are stated with due recognition of the fact that the tensile and impact results were not in every case entirely acceptable. However, the results were of such a nature as to lead to the conclusion that after further study with respect to the location and size of gates and risers, proper pouring temperature, and determination of the most suitable heat treatment, sections could be secured from any location which would uniformly meet the given tensile and impact requirements set forth in this paper. In making this statement, it is recog-

nized that the goal proposed is not necessarily one which can be obtained at once, since a considerable amount of experimentation in foundry practice might be required.

Respectfully submitted,

Steel Division Committee on Test Coupons

J. M. SAMPSON, <i>Chairman</i>	W. C. HARTMAN
FRED GROTTIS	C. F. PASCOE
J. H. LOCKE	H. D. PHILLIPS
V. T. MALCOLM	LT. COMDR. A. J. WELLING

DISCUSSION

. . . *Presiding:* H. D. PHILLIPS, Superintendent, Dodge Steel Co., Philadelphia, Pa. . . .

MEMBER: Mr. Sampson, is there any approved design of test coupon?

J. M. SAMPSON¹: I think many companies today are using the type shown in Fig. 5 of this report—that is, where they are cast separately. Some are even using this same type of test bar, or coupon, merely gated to the casting. Where test coupons are cast integrally, care must be taken to see that the coupon is in such a location that it is properly fed and that there is very little chance for dirt to wash in and remain.

MEMBER: Is there any objection to using a round test coupon cast horizontally with the mold in which you have the casting?

MR. SAMPSON: I believe there is a definite reason for not using a coupon of that kind. It is not the type of casting one would make. Even in the non-ferrous industry, we do not try to do that very often, let alone in steel.

D. C. ZUEGE²: There is not any question in our minds but what a sound metal condition is necessary for good physical properties. However, occasionally we run into these erratic conditions, one of which Mr. Sampson shows in his report. I am referring now particularly to the result on the manganese-vanadium casting at the top of Table 2 of the report. Apparently this test coupon was poured under the same feeder block as the good coupon which he shows directly beneath it. In a case of that kind, we had every reason to expect both of these bars were equally sound. Mr. Sampson indicates that particular fracture was slightly crystalline. This same thing happens a good many times. What I would like to know is why this one bar has these erratic properties? I wonder if Mr. Sampson has any explanation? Apparently that bar was treated as the other bar was when cast from the same type of coupon, and we have a good result in one case, and a poor one in another.

MR. SAMPSON: It so happens those bars which showed the crystalline structure had small amounts of slag inclusions in them. Whether or not that was the reason for the specimens showing that crystalline struc-

¹ Foundry Engineer, General Electric Co., Schenectady, N. Y.

² Technical Director, Sivyer Steel Casting Co., Milwaukee, Wis.

ture, I could not say. I did not see them. I do understand they had enough dirt in them to cause low ductility. The bars were fed properly.

F. A. MELMOTH²: I would suggest that the crystalline appearance of the fracture was due to the type of break. A premature break, caused by the presence of occluded particles of sand, will produce a fracture more suggestive of a brittle material.

Our experience checks with that of Mr. Sampson, in that if we find one grain of sand, or other foreign matter, in the wrong place it is sufficient to ruin utterly any test result. This effect will become even more significant as demands for impact tests become more common—will force our attention more markedly on the production of test coupons, and the methods used to obtain clean sound samples which will indicate with certainty the actual properties possessed by the steel.

E. W. CAMPION⁴: I believe in the present state of our knowledge in the steel castings industry, we should resist perhaps only to a reasonable amount the acceptance of specifications that require the removal of test specimens from the body of a casting, unless it is understood that there are definite limitations. I think it is an obvious fact that a coupon removed from the body of a casting is tested for perhaps several different things. They test the circumstances of design; they test the section of the casting; they test the rate of cooling; they test foundry practice, etc. All of those factors are intermingled and the test results from a coupon taken from the body of a casting groups them all together.

I want to support what Mr. Melmoth said. Over a period of several years, I have seen the results of examples of somewhere from 12,000 or 15,000 test coupons. The fractures of those test coupons were all examined under binocular microscopes. In nearly 100 per cent of the test coupons that were examined, which had relatively low ductility, a grain of sand, a small cavity of some kind or some other local defect was always found some place in the fracture.

I feel that, as far as we have gone at the present time, the acceptance of, or the use of the physical properties obtained from coupons taken from the body of a casting should not be the basis for the acceptance or rejection of an individual casting or lot of castings.

P. E. MCKINNEY³: I think this is a very interesting subject, and I quite agree with Mr. Campion in his views that the physical properties, developed on a test coupon or test bar cut from the body of the casting, are not suitable tests for the acceptance or rejection of the casting. This is true based upon present specifications. I believe even some engineers have the opinion that the physical properties that are usually specified for steel castings are representative of the casting. The real purpose of the coupon is to determine the quality of the metal that has gone into the casting and has nothing to do with the physical properties of the material in any particular location in that casting. The reason, that in certain instances, foundries report such good conformity between coupons and tests cut from the body of the castings, can be ascribed to the fact

² Vice-President, Detroit Steel Casting Co., Detroit, Mich.

³ President, Bonney-Floyd Co., Columbus, Ohio.

⁴ Metallurgist, Bethlehem Steel Co., Bethlehem, Pa.

that the particular design of those castings was such as to effect very ideal conditions of solidification. The location of the test bars, taken from the body of the casting, were in a position that was well fed, but they could not be considered as a criterion of what you might expect of some very poorly fed location in the body of another casting, even of that same general cross section and made of the same material, and heat treated by the same methods of heat treatment.

There are at times rather odious comparisons drawn by people who are uninformed about the meaning of these physical properties of castings, in that they will claim that the castings show better physical properties than forgings of the same material. They fail to appreciate the fact that a test bar is invariably cut from some position in the forging that is going to tell the engineer what the characteristics of that forging are at the point where the test is being made, such as a large generator shaft. It is not at all unusual for the engineer to demand that radial bars be taken right down in the mid-sections of the forging; but at the same time the engineer, instead of asking for 25 per cent elongation in such an unfavorably placed bar, may ask for 10 per cent because he realizes those are the normal physical properties for that location.

I think the work that our Committee on Test Coupons is doing is very valuable, and I hope in time it will give us enough information that we can fearlessly tell the engineer the real facts regarding physical properties of metals in different parts of the casting. I think, we cannot afford to stop this work that is being done by Mr. Sampson's committee, but we ought to do a lot more to bring out just the things that have been shown on this report.

CHAIRMAN PHILLIPS: Unfortunately, it is rather hard to get any of this information. I understand there is plenty of it around but many people do not want to let go of it for fear it will give steel castings, as a whole, a black eye. But as Mr. McKinney has pointed out, the logical thing to do is to get this information and find out what we are getting out of the casting, and then go to the consumer and give him a straight forward picture of the whole thing.

In line with the comment about the size of the test coupons, I believe that is also another study that might reasonably be undertaken by this committee. There is quite a discrepancy in the size of test coupons used in some foundries. Some foundries use a one-inch bar with a short leg and big riser, and others use a two-leg bar, and so forth, and size definitely influences the quality of the metal in that bar. For instance, with reference to a round bar, I happen to know of one foundry that cast a bar round. It was essentially round. It was $\frac{3}{4}$ of an inch in diameter with possibly a $\frac{1}{2}$ -inch feeder running up to the bottom of the flange on this particular casting. Their physical properties were invariably better than anything they got from a standard one-inch wide bar with about a 2-inch leg and a 3 or 4-inch riser on top of it. The size of the test coupon definitely influences the test results you get from the test bar. I would like to know how Mr. Sampson feels about that.

MR. SAMPSON: I have never seen it done, except only to a very limited extent, and the results that I got some twenty years ago when

I tried it, did not quite bear out that same statement. Ordinarily, when we tried to cast a test coupon to the casting, we tried to get it in the upper part of the casting, flush with a good, heavy flange, if we could possibly do so. Of course, in some of our specifications, any casting going over 250 pounds must have the coupon cast with it. Sometimes this is quite difficult. Maybe the heavy section of that casting is only 2 inches. The only thing we try to do in a case of that sort is to get it directly below some riser. And, in many cases, I have found that they definitely expanded the riser out—in other words, widened the flange and widened the riser so as to bring the riser directly over the coupon, the coupon itself becoming part of that flange. In other words, just trying to get away from this very thing Mr. Phillips mentions.

J. W. BOLTON*: Mr. Chairman, in these steel casting specifications, you are facing the same problem that was faced some ten years ago by the gray iron men. At present your coupons are of a given size and you are testing the so-called quality of iron or steel in the ladle, which is a hypothetical measure. You are attempting to draw comparisons between light and heavy sections on the basis of one coupon. You have two or more principal factors: You have the factor of mass or size, which could be evaluated in a separately cast coupon. Then you have the question of tests taken from actual castings where the factor of design is involved, and for which the foundryman cannot be entirely responsible. You run into a number of peculiar conditions there. In the paper by White and Clark referred to in the report, as I remember, the pieces taken for testing from the castings, were taken tangentially, radially, and in various other orientations relating to various parts of the casting. The tests should have been a pretty good measure of actually what happened to the material as it was influenced both by design and mass. Whereas, in the case of Cross and Dahle, it seemed to me that the comparison of the forgings with castings was so set up that it favored the forgings, because the forging specimens were taken in a direction that would show the greatest ductility, whereas with the castings, the orientation was such that it would not produce that effect. In other words, the forging samples were taken with or along the direction of forging, but in service the stresses usually are across the grain.

MR. CAMPION: I heartily agree with Mr. McKinney that it is desirable to continue the work of Mr. Sampson's committee. I think we are all very much indebted to his committee for its work, because it will bring the facts before us in a more definite form than we have heretofore had.

In regard to the round test bars, undoubtedly the round test bars attached directly to some castings are a great success. They are infinitely superior to any other form. There is involved the size of the section; probably somewhere between $\frac{3}{4}$ and $\frac{1}{2}$ of an inch is desirable. There are also involved the circumstances under which round test coupons are attached to the section. There have been hundreds of thousands of them made. The round sections have been adopted in certain cases because they have shown physical properties greatly superior to any other shape.

* Metallurgist, Lunkenheimer Co., Cincinnati, Ohio.

Another comment I would like to make is on the provisions for re-tests in specifications that are generally used. They say that if a defect is disclosed in machining, new test coupons may be submitted. No record, of course, is made of that defective bar. A new one is substituted for it. A defect which shows upon machining, which permits of the submission of a new test coupon, is one that is visible to the eye. Now just move that same little defect a very, very small fraction of an inch under the surface, and a test failure will follow. There is a record made of such a failure. I have always had great curiosity about that provision in most of the specifications.

Fundamental Considerations in Non-Ferrous Sand Control

By G. K. EGGLESTON*, DETROIT, MICH.

Abstract

The author presents some fundamental considerations of sand control for non-ferrous foundries. He first traces the geological history of molding sands showing how deposits were formed. Grain distribution is quite thoroughly discussed and an explanation is given of the system of designating different grain sizes. Effect of grain size on permeability is explained. The clay content of a sand is considered important and the various properties of clays are presented. Benefits of sand control and the essentials of sand control are listed and discussed. Finally, the author describes control as practiced in the plant with which he is connected.

INTRODUCTION

1. The object of this paper is to present an introduction to sand control for those who are not familiar with the principles upon which this work has been based. The information used has been obtained from A.F.A. papers previously published and the writer's personal experiences.

GEOLOGICAL HISTORY OF SANDS

2. In tracing the geological history of molding sand, we find that it is generally believed that the basic rock or material of the earth was granite, and the surface of the earth as we know it today, is some modified form of granite. The principal minerals in granite are quartz, feldspar and mica. The quartz, more commonly known as silica, is by far the hardest of these minerals, and when subjected to abrasion or impact, is not easily broken or splintered, whereas the feldspar and mica, which are aluminum silicates containing some potassium, sodium, magnesium or calcium, are rather soft and easily reduced to a very fine state. As this granite was

* Metallurgist, Detroit Lubricator Co., and Chairman, A.F.A., Non-Ferrous Division Committee on Sand Control.

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For discussion see pages 124 to 129.

slowly eroded away by the elements, principally water in the form of rivers, the feldspar and mica were readily ground to very fine particles by the harder grains of quartz and fragments of granite that were being carried along by the rushing water.

3. When such a river reached a lake, the velocity of the water would be gradually decreased, causing the larger particles (which would be mostly quartz grains) to settle out. This would continue on a graduated scale until the last to settle out would be the very fine silt which would be farthest from the mouth of the river. When such a prehistoric lake finally dried up, the center would, most likely, be a deposit of clay, and as we proceed towards what was the river mouth, the percentage of clay will decrease, more and more quartz grains will appear, and at some spot a desirable combination of quartz grains and clay to make a molding sand might be found. No doubt there would be more deposits of molding sand available if it were not for the fact that the finely ground feldspar and mica must be subjected to just exactly the right conditions or the chemical processes necessary to transform them into clay will not take place.

GRAIN DISTRIBUTION

4. The great number and types of molding sands on the market seem quite confusing at times, but the reasons for this are obvious. Among the principal reasons the following may be cited: The original source of the granite; the distance it was carried; the speed of the river; the size and shape of the lake in which it was deposited. All of these factors tend to vary the properties of the resultant sand. So, broadly speaking, the natural molding sands can be considered to be made up of quartz grains, clay and moisture.

5. The grains of the molding sand control two important properties: First, permeability, which is the ability of the sand to allow air or gasses to pass through it. The figures used to designate permeability indicate the quantity of air passing through a given sample under a standard set of conditions according to a standard test established¹ by the A.F.A. Committee. Second, the finish of the castings is also greatly affected by grain distribution.

Sieve Test

6. The average non-ferrous sand will consist of a mixture of

¹Standard and Tentative Methods of Testing and Grading Foundry Sands, A.F.A., March 1931, pp. 34-45.

grains varying from 40 mesh down to those passing through a 270 mesh sieve. Before proceeding further, it might be well to explain the system of designating the different sizes of grains. The A.F.A. uses¹ the United States Bureau of Standards sieves of 6, 12, 20, 30, 40, 50, 100, 140, 200 and 240 mesh. Starting with the 270 mesh sieve which has an opening of 0.0021 in., each succeeding screen is the square root of 2 or 1.41 times larger than the preceding one, which doubles the size of the openings of every second sieve. The mesh number of a sieve merely refers to the number of wires or openings per inch of screen and does not necessarily have any definite connection with the size of the openings unless some standard system is referred to, such as the Bureau of Standards or Tyler.

7. If a sand is separated into its various grain sizes, it will be found that equal weights of each size will have equal volumes. This is, of course, assuming that the different sizes are of the same general shape and material. This being true, the percentage of voids will also be the same for all sizes, which is about 39 per cent

Table 1

RELATIVE PERMEABILITY OF SANDS OF VARYING SIZES

Mesh	Permeability	Per Cent Voids	Shape of Grains
40	550	39.2	Round
50	341	44.2	Sub-Angular
70	205	46.1	Angular
100	86	47.3	"
140	54	48.4	"
200	36	48.4	"
270	26	47.8	"
Through 270	7	47.8	"

for round grains and 48 per cent for angular ones. As the percentage of voids, or the volume of air passages, is the same for all sizes, one might deduce that the permeability for all sizes might be the same. But, of course, this is not true, as can be seen from some test results listed in Table 1.

Grain Size and Permeability

8. To study more closely the relationship existing between grains of different sizes, a series of lead shot was obtained having their diameters in the same ratio as the A.F.A. screens from 270

mesh to 40 mesh. A special permeability machine of the orifice type was constructed and calibrated to read in figures comparable to those of sand grains of the size the lead shot represented. The permeability of these shot is shown in Fig. 2.

9. An analysis of the relationship between these grains of different sizes reveals that the surface area of a given weight or volume of grains, varies inversely as the diameter, which means if two sizes are taken, such as the 270 mesh and 140 mesh, the 270 mesh being half the diameter of the 140 mesh, will have twice the surface area. Also, the number of grains in a given volume

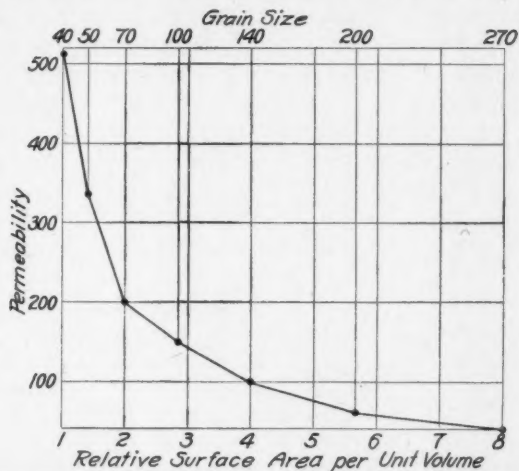


FIG. 1—RELATIONSHIP BETWEEN SURFACE AREA, GRAIN SIZE AND PERMEABILITY.

varies inversely as the cube of the diameter; in other words, there would be eight times as many 270 mesh grains as 140 mesh in a given volume.

10. A study of the flow of air in pipes and orifices does not leave much doubt that the reduction in permeability of the different sized grains is due to the variation in the surface area. The relationship between surface area, grain size and permeability is shown in Fig. 1.

11. Up to now, only conditions where the percentage of voids are the same have been discussed. However, if the percentage of voids is reduced, it has the same effect as reducing the size of a pipe through which air is flowing, and when this is done the flow is very obviously reduced. A rather small drop in voids causes

a relatively large drop in permeability. Fig. 2 shows the results obtained by combining different grain sizes to hold the surface area constant while the percentage of voids has been varied.

Combination of Grain Sizes and Permeability

12. As stated previously, a sand usually consists of a combination of grain sizes. It will be impossible to illustrate all the combinations which might occur. But we want to show some of the combinations which seem most important.

13. If we take 40 mesh grains with a permeability of 500 and add to them 270 mesh grains with a permeability of 40, up to about 30 per cent of the 270 can be added without increasing the volume of the sample, as the smaller grains merely fill in the

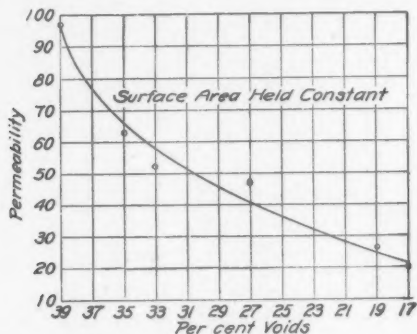


FIG. 2.—PERMEABILITY TESTS OF SHOT HAVING DIAMETERS IN THE SAME RATIO AS A.F.A. SCREENS FROM 40 MESH TO 270 MESH.

void spaces between the 40 mesh grains. Fig. 3 shows the effect on the permeability of combinations of 40 and 270 mesh grains. The very rapid drop in permeability with only a small percentage of 270 grains, illustrates very clearly how a small amount of a fine material can greatly reduce the permeability of a normally open sand. It is interesting to note that a considerable amount of the permeability curve lies below that of the 270 mesh grains.

14. It was a condition similar to this, encountered in our foundry, which prompted making these tests. We had two sands each with a permeability of about 20 and when we mixed them together we had a permeability of 10. Upon investigation it was found that one sand contained mostly 100 mesh grains with enough fines to reduce the permeability rather low and the other was much

finer, mostly 270 mesh, but when combined the finer 270 mesh grains just filled up the voids of the larger 100 mesh grains, thereby lowering the permeability.

15. Fig. 3 shows the effect of adding 70, 140 and 270 mesh grain to the 40 mesh. As the difference in the diameter of the two grain sizes is reduced, the decrease in permeability is much less drastic for small additions of the smaller grains. We think it desirable to have as fine a sand as possible for the sake of casting finish, and it appears one way of doing this and still keep the permeability high enough is to have as many grains as possible nearly the same size. Our specifications call for 75 per cent of the grains to be on three adjacent sieves.

16. Grain distribution has a very marked effect upon the casting surface. The larger the grain the rougher the surface. The closer a sand comes to containing grains of all one size, the more uniform the finish will be. It does not take many large grains mixed into a fine sand to spoil an otherwise good finish, and if finish is an important consideration, the removal of coarse particles of sand or metal should be given considerable thought.

CLAY CONTENT

17. Among the more important properties of a molding sand that depend upon the clay content are green strength, which is the

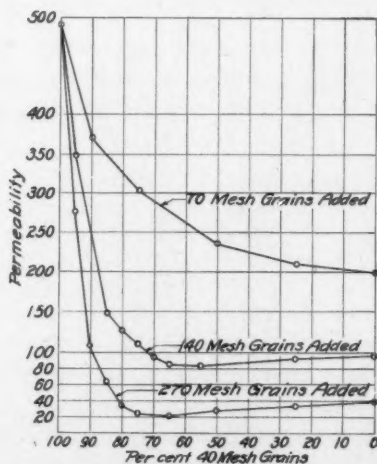


FIG. 3.—EFFECTS ON PERMEABILITY OF ADDING 70, 140 AND 270 MESH SIZE GRAINS TO A 40 MESH SAND.

strength in the tempered or moldable condition. It must be high enough to prevent the mold from deforming after being made. Dry strength is the strength of the sand after the moisture has been removed by baking at about 220° F. This is important because the metal, upon flowing into the mold, dries the sand and if the strength is not high enough in this dried condition, there is the possibility of washing sand into the casting.

Durability

18. Durability might be defined as the useful life of the sand and is governed by the rapidity with which the clay deteriorates or burns out.

Properties of Clay

19. There are six or more different species of clay, each having² separate and distinct properties, such as strength, either green or dry; fluidity, or the property to flow under pressure without breaking; rehydration, the ability to pick up moisture after being dried out; transformation temperature, the temperature at which the clay undergoes a permanent change in composition, thereby losing its value as clay; fusion temperature or the temperature at which the clay substance melts or fuses.

Strength

20. Some species have about three times the strength of others, provided the clay particles are the same size in each case. The particle size must be taken into consideration as the strength and fluidity increase with a decrease in particle size.

Rehydration and Durability

21. The ability of some clays to rehydrate is destroyed at a temperature as low as 400° F., whereas others can be heated to 1000° F. with very little detrimental effect. This property has a great bearing on the durability of a sand. A sand containing a clay which would be destroyed at 400° F. could not be expected to stand up very long, whereas a 1000° F. clay should give very good life.

22. To make the situation more complicated, most sands con-

²Grim, R. E., Bray, R. H., and Bradley, W. F., *The Constitution of Bond Clays and Its Influences on Bonding Properties*, Trans. A.F.A., Vol. 44, (1936) pp. 211-223.

tain two or more species, so that the resultant properties will be a combination of the properties of several species.

23. For example, two sands were taken having the same total clay content. Each was heated to 600° F. for two hours, then retempered and tested, heated to 1200° F. for two hours and again tested. One sample lost 45 per cent of its strength after the 600° F. treatment and 70 per cent after the 1200° F. treatment while the other lost only 10 per cent at 600° F. and 48.2 per cent at 1200° F. The clay of the first sand may have contained about 50 per cent of a clay with a decomposition temperature below 600° F., the other half being a high temperature clay. In use, we would expect such a sand to show a rapid drop in strength when first put into use, then decrease very slowly. The other sand should show a gradual decrease in strength from the beginning. It is obvious that the total clay content is no true indication of the strength or durability of a sand.

24. Unfortunately, the determination of clay species at the present time is not practical because of the expense but some type of durability test similar to that just described is useful.

MOISTURE

25. The moisture content of a sand depends on the amount required to develop the most desirable properties of the clay. Between 5 per cent and 7 per cent is about the range used in non-ferrous sands.

BENEFITS OF SAND CONTROL

26. What benefit might one expect from sand control? First, more uniform and better finish on the castings; second, reduction of scrap due to defects caused by faulty sand, such as washes or blows; third, in some cases the replacement of two or three different sands by one single sand; fourth, the reclamation of used sand which might cut the new sand requirements in half; fifth, the use of cheaper local sands.

BEGINNING SAND CONTROL

27. Where and how should a foundryman start sand control? This might be accomplished in numerous ways with equally good results. The following are the writer's own ideas on the subject, discussed along with the procedure and results of some of the work at the plant of the Detroit Lubricator Company.

28. Uniformity is the most important consideration in sand control; in fact, in any foundry operation. It would be better to have a foundry operation uniformly off color than have it good one day and off the next, because as long as it is uniform you can, in most cases, allow for it, but when it is constantly changing your chances of correcting it are very slight.

29. A good illustration is an experience related by a foundryman several years ago. It seemed that on Monday and Tuesday of each week he had trouble with blows; Wednesday and Thursday, everything was fine; Friday and Saturday the molds dropped and washed. Investigation showed that new sand was being added on Monday A. M. only. This put too much new sand in the heaps for the first two days work and by the end of the week the sand became too weak. When they started to add smaller quantities of new sand each morning, they had good sand all week. This point of small uniform additions of new sand cannot be too strongly emphasized, as it does more to keep your heaps uniform than anything else.

Equipment for Control

30. While some testing equipment is desirable, considerable good can be accomplished by just being careful to make small additions to your heaps at regular intervals. The writer believes additions should be made not less often than once a day or preferably two or three times per day. We find that adding the new sand at the shakeout works quite well. It seems to get mixed into the heap quite rapidly this way.

31. It is possible that some foundrymen have been frightened by the elaborate and expensive equipment offered for sale. While this equipment is desirable to have, it is not necessary to start a sand control program. Excellent results may be obtained from the following inexpensive equipment: A permeability machine; some simple type of strength machine which can be purchased from one of several manufacturers; a means for drying samples for moisture content, for which a small gas oven placed on a gas plate, or the core oven, may be used; scales of about 300 grams capacity and some mason jars in which to keep the samples. These should be all the equipment necessary to start a system of sand control.

Starting Point of Control

32. As a starting point, we would recommend that regular

tests of your present method of handling the sand be made; make one or more tests every day, if time permits. This will give the variations from heap to heap and any changes from day to day, thus establishing an important basis from which to continue experiments. The time and amount of new sand additions should be noted. If any difficulty is being experienced with a certain casting, it should be recorded along with the heap it was made from and the approximate time of new sand additions. After about a month, you should have enough information, if properly correlated, to start a program for improving your sand conditions.

33. From these tests, the variations you are getting can be determined and also what conditions are producing the best casting. This is the condition that should be maintained at all times.

Following up Preliminary Tests

34. If a month or so of preliminary testing has shown that there is more than a reasonable amount of variation in the properties of the sand, efforts should be made to reduce these variations by making your sand additions at definite times and amounts.

Adding New Sand

35. Now, of course, the method of adding the sand to the heap should be given consideration. If a sand mixer is not available, we believe that mixing the new sand in at the shakeout is a good method. If sand mixing equipment is available, mixing about half heap and half new sand together and then making the additions to the heap, works out very nicely.

36. The question of how much new sand can be added to a heap without causing trouble has been asked numerous times. The answer is that it all depends upon the sand.

37. Some sands can be used straight with satisfactory results, while with others additions of 10 or 15 per cent might be the limit. This difference, at least to some extent, is due to the presence of organic material, such as any form of plant life, which will give off a considerable volume of gas when first heated up but will not be affected on continued heatings.

38. If the sand does not give the results which you think you require, even when kept at its best condition, you are up against the proposition of obtaining a more satisfactory sand. But with the information now available, you are in a position to tell the sand producer what you need. For example, if the sand is

satisfactory, except the casting surfaces are too rough, a sand with a smaller amount of coarse grains but with the same permeability and strength may be the solution. In fact, regardless of what the difficulty is, you can now tell the sand producer where the difficulty lies and in most cases he can make very satisfactory recommendations.

39. It is quite possible to have one sand suitable for all the work in the foundry. That is, of course, assuming the same general type of metal is used throughout. We make castings weighing less than an ounce up to 200 lb. without any difficulty, using the same sand. It is merely necessary to select a sand strong and open enough for the largest casting and yet fine enough to produce a satisfactory surface. This may seem like a big order but there are plenty of sands on the market which will meet this requirement.

SAND CONTROL AT PLANT OF DETROIT LUBRICATOR COMPANY

40. The sand control at our plant at the present time is rather simple. The first step is to check the new sand as received. This consists of a screen analysis to check the grain distribution. The strength and durability are checked as previously described.

Sand Cycle

41. The sand cycle in the foundry can be described briefly as follows: The floors are swept after each shakeout. This sand is put through a 4-mesh hand riddle to remove any cores or large pieces of metal. The sand passing through is then put over a double deck screen equipped with an exhaust system which keeps the dust down, but more important, it removes a considerable amount of the fines. In fact, sufficient to keep us from having any difficulty with the fines closing up the sand. This screen is of the vibratory type. The top screen is 12 mesh, which merely acts as a scalper for the rather delicate 30 mesh lower screen. The metal removed by this screening is sent to the smelting department. It amounts to about 0.75 per cent of the foundry melt. The sand passing through the 30 mesh screen is taken to the sand muller where it is mixed with equal parts of new sand. This mixture is then added to the heaps as sand additions are required.

Weekly Testing

42. The heaps are tested once a week for permeability, strength, and moisture. This rather infrequent testing may seem

somewhat lax, but we have used the same grade of sand from the same producer for seven years and, since the present system was put into practice, the maximum variation in permeability has been from 12 to 17 and the strength from 4 to 6 lb., measured in lb. per sq. in. in compression.

CONCLUSION

43. In conclusion we present the following observations:

(1) Grain distribution, rather than average grain size is the governing factor of casting finish.

(2) The permeability is dependent upon the per cent of voids and the surface area of the grains.

(3) The strength and durability of a sand depends upon the species of clay and the size of the particles and not the total clay content.

(4) Sand control should eliminate practically all defects traceable to sand, that were not the result of faulty equipment or workmanship. In our foundry, sand control cuts the scrap losses at least 2 per cent.

(5) In case of casting trouble, the element of sand is eliminated, thereby narrowing the source of trouble to fewer elements.

(6) The use of cheaper local sands is a possibility for considerable savings. The use of such sands might be risky if their condition were not known at all times, but when properly handled, they are superior to a more expensive sand without control.

(7) The re-use of floor sweepings by screening and removal of fines can greatly reduce the quantity of new sand used, in some cases about 50 per cent.

(For discussion see pages 124 to 129.)

Sand Control at the Northern Indiana Brass Company

BY A. C. ARBOGAST,* ELKHART, IND.

1. Approximately one hundred and forty years before Columbus discovered America, there was a bell cast in a Spanish foundry. When this bell was finished, it was found to have seam marks on its surface—this, according to the H. W. Dietert, was caused by the sand containing an excessive amount of clay.

2. This incident happened nearly six hundred years ago, but it still has a familiar ring to anyone connected with the foundry business. In other words, the problem of controlling sand is not a new one, but has been handed down from one generation to the next, each passing it on without making much of a contribution toward its solution. The present generation, however, has attacked the problem in an aggressive manner by originating new testing equipment that makes possible an accurate analysis of sand.

CONTROL BEGINS AT PRODUCER'S PIT

3. The control of sand in our non-ferrous foundry commences at the producer's pits. We purchase our sand from a reputable sand company which controls the quality of their product. We believe that if sand additions are to be made to the heaps intelligently, it is necessary that the supply of new material be under careful control.

4. There are still many small producers who judge the uniformity of their product by the obsolete "hand and eye" method. It has been our experience in the past that it pays to be careful in the purchasing of sand; buying only from reliable companies who put forth an honest, scientific effort to control the quality and the uniformity of their product.

5. We have found it necessary to purchase two different sands to satisfactorily cover the range of our foundry. A sand with an average A.F.A. grain size of 157, and with a clay content of 18.8 per cent is used on our larger castings; these larger castings consisting of six to fourteen inch fittings and heavy flanges with an average weight of about thirty pounds.

* Vice President, Northern Indiana Brass Company.

NOTE: This paper was presented before Non-Ferrous Sand Control Session, 41st Annual Convention, Milwaukee, Wis., May 6, 1937.

For discussion see pages 124 to 129.

6. The second type of sand purchased has an average A.F.A. grain size of 188. The clay content is about 13 per cent, the moisture 5 to 7 per cent, the permeability 10 at 6 to 7 per cent moisture and the green compression strength 5.4 lb. This sand is then blended with the other sand and is used on our smaller castings. The average weight of these castings is about $\frac{3}{4}$ lb. each.

7. Since the smaller castings comprise the larger portion of our output, the majority of the heaps in the foundry are made up of this blended sand. The blending of our own sand greatly increases the versatility of our foundry and permits a fineness of regulation that would be impossible to obtain in any other way.

LABORATORY CONTROL

8. Our foundry is equipped with a complete laboratory where it is possible to analyze our metal and to determine the quality of our sand. The Dietert system of sand analysis is followed in our laboratory and all the test data given in this article were obtained on Dietert sand testing equipment.

9. A complete test is made on the sand twice a week and more often if the foundry superintendent deems it necessary. A test is made on every heap in the foundry for moisture, permeability and green compression strength.

Sand for Small Castings

10. We have found that the sand that we use for our smaller castings gives best results when the moisture is from 6 to 6.5 per cent with a permeability of 13.5 to 15.5 and a green compression strength of 6.2 to 6.7. These figures establish for us a permissible tolerance of a few points each way and we put forth a determined effort to control our sand within these limits.

Large Castings

11. The sand used for our larger castings is of a higher permeability with limits of about 17 to 21. The moisture and the green compression strength are also higher with a moisture of about 6.7 per cent and a green compression strength of 6.4 to 7. These limits have been giving us excellent results and by frequent checking of the heaps the sand is not difficult to control within these figures.

Supervision of Control

12. The analysis of our sand is made by the foundry control

department and the results reported to the foundry superintendent. He is in complete charge of the sand control program and is held responsible for the condition of the heaps. All additions to the heaps are supervised and regulated by him. He has at his fingertips a complete knowledge of the exact condition of each pile and from this information he is able to make additions to the heaps in an intelligent manner.

13. Since the results of sand control depend largely upon the ability of the individual to use the data intelligently, we feel that it is wise to have a man of ability and practical foundry experience to interpret the sand control test data. In this manner every heap in the foundry is guided by an experienced hand—not just by the experience gained from one particular heap, but by the experience gained from every heap in the entire foundry.

14. We have found that through sand control we can produce better castings at a lower cost than was possible in the days gone by when our molders tested their sand by the feel of it.

REDUCTION OF LOSSES BY CONTROL

15. In 1934, before we were equipped to practice sand control, our leaker loss was over one per cent. The castings are submitted to a test of 90 lb. per sq. in. under water and the leakers were scrapped. In 1935 and 1936, we were able to cut this loss to less than $\frac{3}{4}$ of one per cent by the diligent use of sand control. Our other foundry losses lowered proportionally and we noticed that our casting surfaces were greatly improved.

16. In conclusion, we wish to state that it has not been our intention to give the impression that a good molder doesn't know his sand. He does. But he can't tell moisture, permeability and green compression strength, to keep his casting losses low so that one can get by in this highly competitive business of operating a foundry.

DISCUSSION

Presiding, H. M. ST. JOHN, Chief Metallurgist, Detroit Lubricator Co., Detroit.

CHAIRMAN ST. JOHN: Those of us who have followed the sand work of A.F.A. over a period of years may have received the impression that much of this work is very theoretical and elaborate. That is true, necessarily. The rather intricate and involved experiments that have been carried on have yielded tests which the foundryman can apply in his own foundry.

The particular point I would like to make is that to realize the bene-

fits of sand control, not all the tests that have been suggested need be applied. The average foundry can gain a very large part of the total possible benefit from sand control by the application of a small number of simple tests. That is particularly true after a little experience has been gained.

No foundryman needs to be dismayed or discouraged from starting sand control by the fact that sometimes control is carried out in a very elaborate fashion.

W. M. BALL, JR.¹: I would like to present a sand problem that we have encountered. About a year ago we installed a sand conditioner of the muller type; we had been using the vibratory method of conditioning our sand. The first problem we ran into was scabbing. We made a first test, making castings directly from the mulled sand, then a second test aerating the mulled sand before using it, and a final test going back to our old process of just aerating and conditioning the sand.

We took a sand sample of each batch and had them tested at two different places. All samples had same physical properties. However, in the resultant castings, the only good castings obtained were those made by our old aerated vibratory process.

This, I find, is true not only in our own foundry but in other shops where they are mulling sand. There evidently is a difference in the sands but the difference is not shown in the physical tests. There is some sand property that is eliminated by the mulling processes, which these tests do not show.

H. W. DIETERT²: Mr. Ball has brought out a very interesting point. When you mull fine sand, you can over-mull it. If you use a muller, raise the wheels of the muller so that they just barely turn. Then, if the muller is working in a sand system, do not run the muller more than two minutes per batch.

The reason that your sand worked better when you aerated it is that when you riddle sand and then ram it in the mold, the mold is softer and more open regardless of how hard you ram that sand. Aerated or riddled sand will always be more open than a sand that has not been aerated even when the sand is taken from the same heap or from the same batch.

The reason why the physical tests did not show a difference in mulled and unmulled sand was because you did not measure the deformation of the sand. If you had measured the deformation of the mulled and unmulled sand, the two tests would have shown different because as sand is mulled, the plasticity is increased and must be decreased in some manner (aerating or riddling) to give the proper mold properties.

If you are working with a fine grain structure and the muller has compacted it more, sand expands and when it expands something has to happen. If your sand is hard and tight in your mold, it is going to break the mold surface. If you have it aerated, the mold is full of little pore surfaces and the sand grains can slip into these pores.

E. J. BUSH³: In paragraph 42 of his paper, Mr. Eggleston admits that they are lax in their testing, but I cannot understand why the

¹ Supt., Edna Brass Mfg. Co., Cincinnati, Ohio.

² President, Harry W. Dietert Co., Detroit, Mich.

³ Naval Gun Factory, Washington, D. C.

permeability, moisture content, etc., should be tested and adjusted one day and the rest of the week be allowed to run along to suit itself. I have been unable to have sand act that way for me.

MR. EGGLESTON: We have found after years of experience that when new sand of a constant analysis is added to our heaps in definite amounts, and at regular intervals, the grain structure or bond of our heaps will not change enough in one week to be noticeable.

Where we have 12 or 15 separate heaps of sand and each one being used four or five times per day, the control of the moisture has to be more or less left up to the moulder. If all the properties of the sand are constant except the moisture it is not difficult to recognize the proper moisture content by feel, but if the grain distribution and clay content of a sand are constantly changing even the laboratory will have difficulty determining what the proper moisture content should be.

Our laboratory tests are made merely to determine whether the sand in the heap will have the desired molding properties provided the proper moisture content is used.

Where a central sand handling system is used the control of moisture should be very simple and controlled within very narrow limits.

CHAIRMAN ST. JOHN: I might say that anyone starting a system of sand control, as suggested in this paper, needs to test sand frequently at the beginning, even two or three times a day is not too much. If, as time goes on, it is found that conditions have become uniform and satisfactory results are being obtained, the frequency of tests can be decreased. Testing should never be discontinued, but it becomes a matter of testing each heap possibly once a week, just to make sure that the sand is being taken care of properly.

Of course the minute any sign of trouble appears in the casting from a certain mold which can be attributed to sand, then it is time to get after that particular heap.

D. F. O'CONNOR⁴: Mr. Eggleston brought out a very important point which I think should be mentioned again. We are probably using separate sand heaps in the production of our castings and, therefore, the problem of education comes in. It is true that you take your moisture test each day—or several times a day—and obtain certain results but if you do not have careful supervision, the helper or the man who is wetting down the sand may add too much water. If excess moisture gets into the facing sand and against the pattern, there is no doubt but what pit-holes are going to show up, especially under the skin of the casting.

A simple and practical way of training men to wet the sand properly for medium size castings, is to spray a little water on the molds after removing the castings. Then dump in the sand heap, cutting around with a shovel to allow steam to escape; then riddle through a No. 4 mesh. If you find that the sand goes through the riddle readily, you may obtain a moisture of between 4 and 6 per cent. If you find that in going through the riddle it will not go through fairly fast, you can determine immediately that it is too wet. Eventually the helper is trained to add the proper amount of water.

⁴ Supt., Brass Foundry, Walworth Co., South Boston, Mass.

If at that particular point you instruct the helper to throw the sand back into the heap and add some dry sand—or open it up somewhat—that will cut down the moisture content and prevent defective castings. However, you still have to control moisture content in a more elaborate way to get the necessary amount of good castings from that simple method. Some castings may require more, some less moisture content, depending on the type of casting and the alloy to be poured. This would require frequent testing. The point to bring out is the simple way of controlling moisture if you do not have a sand testing outfit.

The education of men, especially in non-ferrous foundries, is one of the important things which we have to deal with today. It is rather hard to make the men realize that adding too much water will produce poor results.

MEMBER: Regarding the muller type mixer, I might state the experience we have had. Starting the first of the year, we put in a new sand system. We run our sand on a shakeout belt, up to an elevator, into a sand storage and there through a muller type mixer. We mill our sand about 2 minutes. We control our moisture at the mill and our sand goes through another elevator, up through an aerating machine, and back in a belt to the hoppers for the molders.

We have equipment for testing the sand and it has been very interesting. Our biggest point of trouble has been with moisture. On one particular automobile job, we were having trouble. By controlling our sand moisture between 5.5 and 6.3 per cent, we gained wonderful results and cut our loss down to almost nothing.

I defy any molder to find out how the moisture is running in the sand without sand control instruments. We check our sand sometimes twice and sometimes three times a day.

One of our great troubles was the fines in the sand. Our problem was to get rid of them. All we did was to put a 12-in. pipe on the top of our elevator and a natural suction of the sand going up the elevator would pull the fines out of the sand. By leaving the pipe open for a week, we can get our sand almost as coarse as core sand, and by closing it we can get almost any degree of sand fineness we want.

How far we are going, I do not know. We have only had this layout since the first of the year and we are playing with it. We add our new sand right in our mixers. If the sand is getting weak, you can add a stronger bonded sand.

MEMBER: Evidence accumulated indicates that sand used in non-ferrous foundries is mostly natural sand. A great deal of time has been devoted to the production of synthetic sands for other types of foundries and we have been considering whether foundrymen in your industry would be interested in the production of synthetic sands to meet the requirements of your industry and whether you would prefer to have those sands tailor-made and delivered to you or would you prefer to make them in your own plants, using the ingredients, grain sizes and materials to accommodate your own particular problem.

CHAIRMAN ST. JOHN: Three types of sand are available for use in the foundry, or three different methods of operating. One is the old,

time-honored method of finding a natural sand that seems to be suitable for your work and using that more or less as is. The second method is using a combination of two or more natural sands, either of which is not entirely suitable of itself but blended in such fashion that the combination gives good results.

The third, of course, is the synthetic sand in which an artificial or natural bond is added to the sand. The latter two methods, of course, could be combined. By one or the other of these latter two methods, practically any desired sand combination can be obtained and maintained.

Another point, there is a difference between foundries which operate with separate heaps for molders, where the sand is used over and over again in the heap, and a foundry where the sand, after the shakeout, is taken through the sand-treating system and returned to the molder. It is possible that the use of a synthetically bonded sand is somewhat more successful where you have a sand-treating system than it is where you operate with floor heaps which are not treated after each use.

A. J. MESSMER²: We are not a large foundry but after using natural sand from many localities, some with good but expensive results, we went to a blended sand that gave good results. However, the blended sands were not uniform and we finally turned the problem over to a synthetic sand company. They shipped us a trial lot of sand made up to specifications obtained from the analysis of a sample of our blended sand and the results were fine. We have used many a car of it. We have been doing that for about 3 or 4 years and the results are uniform.

We use a sand conditioning unit and such a thing as scabs, when the molder has done his part right, is practically a thing of the past with us.

Our castings are mostly small. They run from $\frac{1}{4}$ to possibly 1-lb. each—mostly squeezer work but the castings with which we had scabbing trouble would probably run 2 to 3 lb. each. The scabbing was eliminated. They are required to stand a pressure of 500 lb.

MEMBER: I do not think size has anything to do with making sand that will accommodate your casting. You can make castings of half an ounce or five tons if you have the right sand.

MR. O'CONNOR: I think we would benefit somewhat if we did have a synthetic sand, because there we are able, with the sand control equipment, to really determine our grain size. Then if we add a definite amount of clay or bentonite or other bonding material, we are surely producing something that we know about, whereas, in natural sands, we are bound to find some variation here and there that is probably causing the defect but we cannot trace it.

MR. ARBOGAST: Several times we have attempted to use synthetic sand and we have abandoned it each time and gone back to the natural sand. I make what I think is a practical suggestion to the sand people—that they determine or carry on some tests on non-ferrous castings with these synthetic sands and at the next meeting present some definite conclusions of what their results have been so we might be governed accordingly.

² Treasurer, Messmer Brass Co., St. Louis, Mo.

MEMBER: We have a very small foundry, probably six molders. I do not use a synthetic sand but ground rock. I have tried a little experiment to reclaim the sand.

I heard mentioned here something about taking out the fines. We are trying that same thing. We are running our sweepings through a 32 riddle, protected by a coarser riddle on the top, and underneath I am experimenting with different velocities of air to carry the fines off and then taking the coarser grains of sand that are going through and adding a percentage of bentonite. So far it has not caused me any difficulty. Of course, I am watching to see just exactly what is going to happen over a long run of time.

I am saving possibly three-quarters of the sand that is going into the heap. Our burned out clays and silt will really go through the fan. I do not as yet have the correct velocity. If anybody here has something similar, I would appreciate knowing about it.

I have had wonderful success with the ground rock inasmuch as I can specify just the grain I want and the amount of clay I want and get it that way.

MR. EGGLESTON: I would like to add that after we have screened our floor sweepings through a 30-mesh screen, if they are tempered and tested, we find they test up better than the sand in the heaps does.

Report of Committee on Heat Treatment of Steel Castings*

To Members of the Steel Division, American Foundrymen's Association:

Your committee on heat treatment has been assigned the task of reviewing the status of the heat treatment of steel castings and of describing briefly any outstanding developments occurring during 1936 in this metallurgical field.

Unfortunately, the past year produced no important new processes or methods of heat treatment having a direct and economical application to the steel foundry industry.

The most important 1936 development in the heat treating field was the "Tocco" process of differential hardening by induction heating. In this process specific sections of steel castings, forgings or other steel parts are quickly heated by electricity to above the critical range and are immediately quenched, thus hardening the heated portions but maintaining the original properties in the unheated portions. Although this process has many advantages over previously existing methods it requires elaborate and costly equipment and, therefore, is not applicable to the product of the jobbing steel foundry but rather to steel foundries where mass production of a certain design is assured.

The fact that there were no new developments during 1936 of which we are aware does not indicate that no progress was made in the art of heat treating steel castings. On the contrary, considerable advancement has been made in the refinement of existing processes and their greater application to designs which a few years ago would have been considered unsuitable for liquid quenching.

The increased use of alloy cast steels has emphasized the necessity for developing from any specific chemical composition, the utmost in physical properties. The practice of improving the shock toughness of these steels by batch quenching to be followed by a high draw is being used to a greater extent than ever before.

Considerable improvement has been made in specific methods for differentially hardening castings so that certain portions may be hardened for wear resistance while the other parts are main-

* Presented before Steel Division Session, 1937 Annual A.F.A. Convention, Milwaukee, Wis.

tained soft for machinability or tough for resistance to shock. The desired results are obtained either by differential heating or differentially quenching or both and today in some instances, carefully controlled differential heating, followed by an accurate time quench, is consistently producing steel castings having as many as three brinell hardness ranges in the same casting. Differential quenching is obtained by either spraying, spinning or partial immersion in the quenching medium, and considerable ingenuity has been exercised in the construction of fixtures to perform these various operations.

Differential heating is secured either by heat lagging or by locally heating by means of the oxyacetylene torch. The latter method is commonly called "flame hardening."

Articles on this subject were published in issues of *Steel* for Nov. 9, 1936, and Nov. 30, 1936, by G. V. Slottman and R. L. Rolf, respectively. The articles are summarized below:

(1) "*Localized Surface Hardening*" by R. L. Rolf, consulting metallurgist, Cleveland, and metallurgical engineer, Lakeside Steel Development Co., Cleveland. The author points out that the so-called "Shorter Process" has assumed wide commercial importance for localized surface hardening. While for mass heat treating of small objects the furnace method is the most efficient and economical one, there are many instances where, due to size or danger of distortion, the oxyacetylene flame hardening method can be used to advantage. Analysis of steel is important; for straight carbon steels carbon should be 0.40 to 0.70 per cent. Steels of S.A.E. series Nos. 1300, 3011, 3200, 3300, 4100, 6100 and Chromansil with carbon 0.25 to 0.45 as well as S.A.E. 5100 with carbon 0.20 to 0.35 per cent have been successfully hardened.

For best results parts to be surface hardened should first be heat treated by quenching and drawing to a sorbitic structure or by normalizing to produce a grain-size closely approaching the heat treated structure. In the process, the surface of the material is brought rapidly to the desired temperature by the oxyacetylene flame and immediately quenched, permitting practically no time for diffusion. Quenching medium is mostly water, for more drastic quench brine solutions, for less drastic quench hot water, soap solutions, soluble oil or air blast. With extreme hardness on the surface, original strength and toughness of core is retained. Stress relieving at 250 to 300° F. after quenching is recommended.

The two principal methods of hardening, progressive and by spinning, are discussed. Speeds for progressive hardening are given at 4 to 10 in. per minute and range of revolutions for the spinning operation at 70 to 150 R.P.M.

Eleven photographs including pictures of the Monitor and Gleason flame hardening machines illustrate the process.

(2) "*Flame Hardening Presents Economical Heat Treating Method*" by Dr. G. V. Slottman, Air Reduction Sales Co., New York. After short discussion on advantages of process (same as above) author discusses different types of torches for hand or machine operation. Multiple flame heads generally are provided with a row of quenching holes following the heating holes and, for particular jobs, special heads can be designed. Parts which have been successfully hardened include gears of the herringbone, spur, spiral, bevel and sprocket types, crankshafts at their bearing surfaces, cams, roll necks, wabblers. Author also points out that flame hardening of guides for machine tools, locomotive crossheads, drilling heads, punching and forming dies, etc., may be mentioned as potential fields of applications. The article contains seven photographs showing torches, work set-up for flame hardening and results obtained.

Your committee believes it appropriate to point out that there has been a greater tendency to apply a heat treatment to unfinished castings often known as a preheat or pre-anneal. This treatment, usually in the nature of a full anneal, has for its purpose the elimination of stresses set up by unequal cooling in the cast condition or by localized application of extremely high temperature, as in the removal of risers by the oxyacetylene torch, and is generally applied to steels of the air hardening type and which are quite temperamental in the "as cast" condition. Knowledge gained from experience with the different designs as found in various chemical compositions is the guiding factor in determining when such treatment shall be used.

In regard to heat treating furnace equipment no significant developments have occurred during the year. Controlled atmosphere furnaces for scale elimination have not as yet had a favorable reception by steel foundrymen because of their high cost and the nature of steel casting heat treating methods. Neither have many of the recirculating-air-type draw-furnaces been installed.

Your committee wishes to direct your attention to the *Recommended Practices for the Heat Treatment of Carbon and Alloy*

Steel Castings published in the 1936 edition of the AMERICAN SOCIETY FOR METALS handbook. Because of the concise manner in which a large amount of information is presented this work serves as a very valuable reference for the steel foundry heat treating department.

And finally it is considered appropriate to mention the advancement to standard of A.S.T.M. specification A 148-36, which for three years previous had existed as a tentative standard in the AMERICAN SOCIETY FOR TESTING MATERIALS. This specification covers "Alloy Steel Castings for Structural Purposes" and Class C, consisting of three grades, refers specifically to liquid quenched castings.

Your sub-committee wishes to report that its activities in cooperation with the sub-committee on Heat Treatment of Steel Casting of the AMERICAN SOCIETY FOR METALS, through its representative on that committee, have not functioned yet due to the fact that the sub-committee of the AMERICAN SOCIETY FOR METALS is in the process of reorganization with Major R. A. Bull as chairman. As soon as this reorganization is completed, the cooperative activities will be started.

Respectfully submitted,

Committee on Heat Treatment

A. N. CONARROE, *Chairman*

WERNER FINSTER

DAVID ZUEGE

Sand Control in a Malleable Foundry

By E. C. ZIRZOW*, CLEVELAND, O.

Abstract

This paper gives a detailed description of sand control as practiced in the plan with which the author is connected. Factors of molding sand control are listed after which an outline of the mechanical method of handling the molding and core sands is given. Routine testing methods for molding sands, facings and core sands are discussed. Factors in checking new sands, clays and binders are described. Next details of controlling system sands are given, discussing these under grain fineness, fines, moisture and moisture control limits, bond control, sea, facings and fuel oil use. The use of fuel oil in the sand has been used with a marked degree of success. Control of core sands is discussed under headings of fineness, green permeability, green bond strength, dry bond strength, baking control and variations in control and mixtures. Charts present data on properties as variations over stated periods.

INTRODUCTION

1. No claim is made that the methods of control of malleable foundry sand described in this paper are original. There are several foundries which have systems quite similar to the ones described in this paper. Ideas have been exchanged as to the proper methods of control with the result that these methods are quite similar. There are, however, some variations in the desired properties of the sand. This paper, therefore, will deal chiefly with the results that can be accomplished by proper control.

* Chief Chemist, National Malleable and Steel Castings Co.

NOTE: This paper was presented before the Malleable Cast Iron Session of the 41st Annual Convention, Milwaukee, Wis., May 5, 1937.

CONTROL FACTORS

2. In the control of molding sand there are certain factors that must be kept in mind. The sand:

(1) Must be prepared so that it can be easily worked by the molders to reduce molding losses to a minimum,

(2) Must produce sharp, accurate contours on the castings,

(3) Must give sound castings, free from blow holes, scabs, cuts, pin holes, cold shuts, and other defects,

(4) Must give smooth surfaces on the castings,

(5) Must clean easily from the castings so as to reduce cleaning costs and

(6) The cost must not be excessive.

3. There are other factors such as metal, design of casting, type of molding machine, bottom boards, etc., which enter into the proper control of sand but do not apply directly. In this paper, the assumption will be made that these factors have been taken care of in the proper manner.

CORE SAND HANDLING

4. Sands used in the core room are put through a drier before being used. From this drier, they are conveyed to the various small bins in the core room. Two bins are provided for each type of core sand. Sand is used from one bin while the other is being filled to eliminate the necessity of using hot sand. The core sand mixtures are prepared in paddle type mixers, each equipped with a rotary screen. The cores are baked in continuous vertical type core ovens.

MOLDING SAND SYSTEMS

5. There are several sand handling systems in the plant, which are essentially alike. The sand is fed from a 75-ton hopper to the elevating or tempering belt. The first amount of tempering water is added at this point. As the sand travels upon this belt, raw sea coal and rebonded sand are added continually from small hoppers. From this belt, the sand goes into the pug mill where the final addition of water is made. From the pug mill, it drops into the revivifier, from where it falls upon another transfer belt. The sand is taken from this belt by a series of plows to the molders hoppers, surplus going over the tail spouts onto a reciprocating conveyor belt at the shakeout.

6. The molds are dumped at the shakeout onto a vibrating screen which removes the sand and cores from the castings. The sand is carried over the magnetic pulley and then falls on vibrating screens to remove pellets of iron, clay balls, and core particles. After passing the vibrating screens, the sand goes back to the storage tank.

ROUTINE TESTS

System Sands

7. Routine tests for moisture, permeability and bond are run on all system sands every half hour. Total carbon content of the various system sands is determined twice each day. A sieve test is run on each system sand every other day. On this test, no attempt is made to remove the clay or sea coal from the sand. True screen tests are run once each month.

Facing Sands

8. Facing sands are tested periodically throughout the day. The foundry sand tester works in conjunction with the molder foreman and labor boss. He must see that all his sand handling equipment is in good shape and functioning properly, and that the proper facing is being used.

Core Sands

9. Core sand mixtures are tested twice each day for moisture, green permeability, green bond, and dry bond. Dry permeabilities are tested periodically.

10. The core sand tester must see that the ovens are at the right temperature, see that the baking cycle is correct, note condition of cores and see that the right core sand mixture is used. He must work in close harmony with the core room foreman and see that no improperly baked cores go into the foundry.

Duties of Chief Sand Man

11. The chief sand man makes all changes in molding and core sand mixtures. He sets up the various moisture, bond and permeability limits; determines any changes to be made in raw materials; runs all experimental work and checks all casting defects caused by sand.

12. Investigational work is carried on continually on foundry and core sands.

SELECTION OF NEW SANDS AND MATERIALS

13. Of prime importance is the proper selection of the new sands. We use three basic new sands having the typical screen analyses as given in Table 1.

Table 1
TYPICAL ANALYSES OF NEW SANDS—SCREEN TEST

Mesh No.	Amount of Grain Remaining on Screens		
	Sand A Per Cent	Sand B Per Cent	Sand C Per Cent
On 6	0.0	0.0	0.0
12	0.0	0.0	0.0
20	0.2	0.0	6.0
30	0.3	0.0	40.0
40	1.5	2.5	41.0
50	2.5	15.5	10.5
70	13.5	54.0	2.0
100	41.5	26.0	0.5
140	11.5	1.5	0.0
200	24.5	0.0	0.0
270	3.5	0.0	0.0
Pan	1.0	0.0	0.0

Sands

14. Tests are run on every car of sand received, and the cars are released only after the screen test has been determined. It is interesting to note that on sand *A*, the largest percentage passes through a 70 mesh screen; on sand *B*, the majority of the sand passes through a 40 mesh screen, and remains on the 70 mesh screen; on sand *C*, 85 per cent remains on the 40 mesh screen.

15. The sands are used for making cores as well as in the foundry molding sand. Sands *A* and *C* are used chiefly for closing or opening the sand. With the grain selection given above, this is quite readily accomplished, as there is very little overlapping of grains among the three sands.

16. These sands all have fusion points of over 3100° F. The grain runs from sub-rounded to sub-angular. There is little or no natural bond present.

Clay

17. Every car of clay is tested for green tensile strength. A minimum green strength is specified. These tests are run at optimum moisture content. A fineness test on the clay is run periodically.

Sea Coal

18. Sea coal is tested for volatile combustible matter, ash, and fineness.

Core Binders

19. Cereal binders are tested for green strength and loss on ignition; a weight per volume test is also run as all cereal binders are used on a volume basis.

Dried Cores

20. Core dry binders are tested for dry strength. A check is also run on the baking temperature and cycle. A weight per volume check is made weekly.

CONTROL OF SYSTEM SANDS

Grain Fineness

21. Grain fineness of the system sands is determined mainly by the core sand. Approximately 90 per cent of the cores go into the systems at the shakeouts. No effort is made to remove fines, but some of the fines are removed on top of the storage tank in the screening operation. Some are carried over the cooling conveyor on the surface of the castings and are removed at the rolling barrels.

22. Typical screen analyses of two of our systems are given in Table 2. The screen analyses of Table 3 were taken on these two sands before the removal of the clay and sea coal.

23. Sand No. 1 is an open system sand used for castings weighing from 100 to 350 lb. The cores used are made from a blend of new sands *B* and *C*.

24. Sand No. 2 is a fairly fine system sand used on the majority of castings whose weight runs from $\frac{1}{4}$ to 20 lb. The cores used in this system are made from either new *B* sand or a blend of *A* and *B*.

25. Fig. 1 shows the grain fineness control on these two sands over a period of one month. The fineness numbers used were determined on the sand before the removal of clay and sea coal. The desired fineness on sand No. 1 is 40.0, on sand No. 2 is

55.0. These numbers are only a rough guide to quality. The grain distribution must be watched and be held as constant as possible. The fines in particular must be checked constantly.

Fines

26. Fig. 2 shows the fines control over the same period. The actual percentage of fines is about twice as high. This would give

Table 2

TYPICAL SCREEN ANALYSES OF TWO SYSTEM SANDS

Mesh No.	System No. 1 Per Cent	System No. 2 Per Cent
On 6	0.0	0.0
12	0.1	0.2
20	1.5	0.5
30	9.4	2.1
40	17.0	6.2
50	2.0	1.2
70	34.6	43.8
100	12.0	18.0
140	7.0	8.8
200	1.6	2.2
270	0.8	1.4
Pan	1.4	2.6
A.F.A. Fineness No.	55.0	70.0

Table 3

SCREEN ANALYSES OF TWO SYSTEM SANDS BEFORE REMOVAL OF CLAY AND SEA COAL

Mesh No.	System No. 1 Sand Per Cent	System No. 2 Sand Per Cent
On 6	0.0	0.0
12	0.5	0.0
20	5.5	1.0
30	18.0	3.0
40	25.0	11.5
50	17.0	22.0
70	18.5	33.5
100	12.0	21.0
140	2.0	5.0
200	0.5	1.0
270	0.0	0.5
Pan	1.0	0.5
Fineness	42.0	53.0

a figure of about 6.5 per cent fines as the maximum percentage for this month. This checks the A.F.A. fineness test which shows a percentage of 6.2.

Permeability

27. Permeability is governed by the following factors:

- (1) Amount of core sand.
- (2) Fineness of core sand.
- (3) Amount of active clay.
- (4) Moisture content.
- (5) Amount of fines burned clay, sea coal, etc.
- (6) Amount of sea coal.
- (7) Grain Distribution.
- (8) Temperature of sand.
- (9) Aeration of the sand.

28. The amount of burned or "dead" clay depends upon the

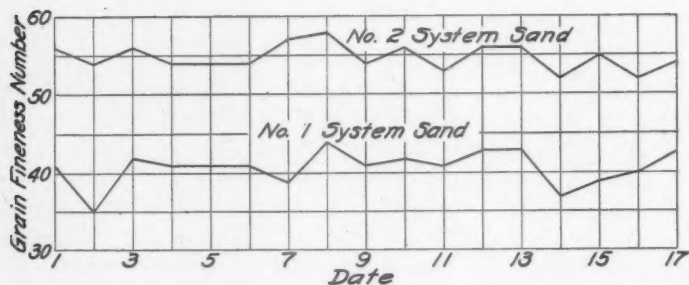


FIG. 1—GRAIN FINENESS CONTROL OF TWO SANDS OVER A PERIOD OF ONE MONTH.

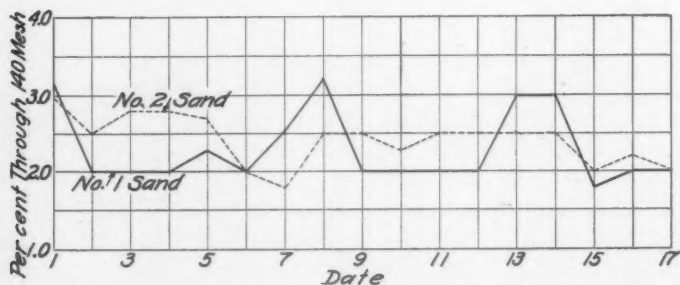


FIG. 2—CONTROL OF FINES OF SANDS OF TABLE 1 OVER SAME PERIOD.

type of castings and how they are shaken out. The temperature at which the metal is poured is also important. The majority of this clay in the systems is carried on the surface of the (red) hot castings and is removed at the rolling barrels. The same conditions exist in regards to the ash from the sea coal.

29. The chief control of permeability is through the core sands. Permeability can be controlled through the addition of new sand in the rebonding sand. This method is used only as a last resort due to the increased cost from the necessity of using new sand.

30. Fig. 3 shows a typical day's run on permeability on the two systems using sands Nos. 1 and 2. On sand No. 1 the desired permeability is 75 plus. On sand No. 2 the permeability range is

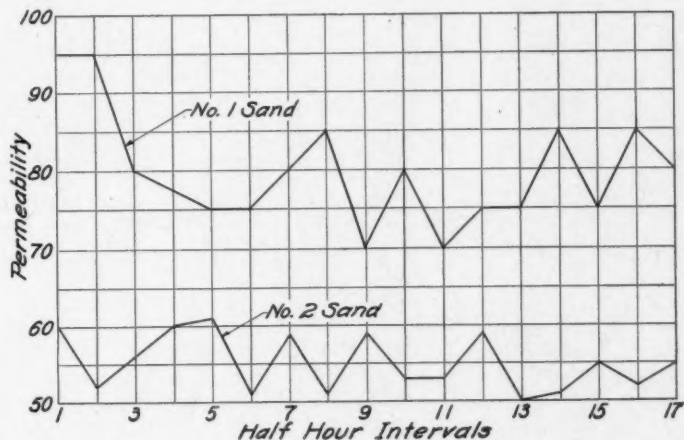


FIG. 3—PERMEABILITY OF A TYPICAL DAY'S RUN OF TWO SYSTEM SANDS.

50 to 60. On sand No. 2 there is good control with very little variation. On sand No. 1 the control is not quite as good. The rather great variations in No. 1 sand are due to a greater variety in the class of work supplying variable amounts of core sand at the shakeout.

31. The permeability tests along with the grain fineness tests give a fairly complete picture of the venting property of the sand. Foundry losses due to blows, scabs, and rat-tails caused by too low a permeability have been practically eliminated.

Moisture

32. To control moisture content of the system sand, the following factors have to be taken into consideration:

- (1) Amount of overflow sand from spillways and tail spouts.
- (2) Amount of shakeout sand.
- (3) Amount of sand being used.
- (4) Temperature of sand.
- (5) Atmospheric conditions.
- (6) Amount of clay in sand.
- (7) Fineness of sand.
- (8) Amount of fuel oil in sand.
- (9) Mixing conditions.
- (10) Amount of sea coal.

33. In the sand systems, the moisture is added in two places. The greater part is added at the large feed table, the last 0.3 to 0.4 per cent are added at the pug mill. The reason for adding the greater percentage of the water at the feed table is to allow more soaking time. The final addition is made at the pug mill. This insures closer control as it puts the final water addition nearer to the sand temperer.

34. Proper moisture control and proper moisture limits are absolutely essential for good sand control. Definite moisture lim-

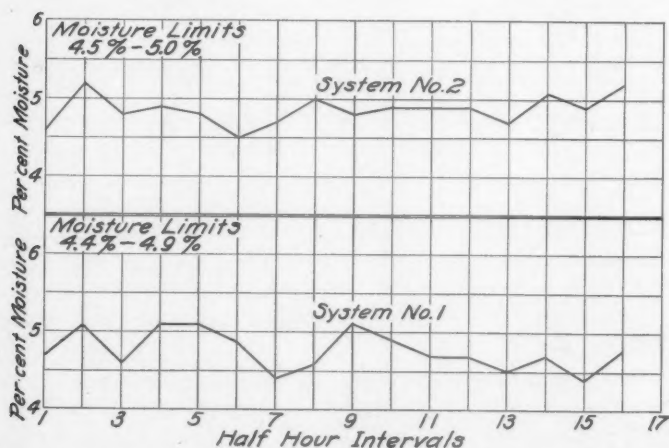


FIG. 4—MOISTURE CONTROL OF TWO SYSTEM SANDS OVER AN EIGHT HOUR PERIOD.

its must be set for each system taking all of the above factors into consideration.

Moisture Control Limits

35. Fig. 4 shows the moisture control over a period of 8 hours. The moisture limits are almost identical for the two systems. Smaller limits would be more desirable but we have found it to be almost impossible to control sand within a smaller range. There are the ten possible variables recorded above to be considered besides break downs. Break downs usually necessitate holding the castings in the molds longer than usual, causing a greater volume of sand to dry out, and this also causes the temperature of the sand to rise.

36. These moisture limits are about one per cent above the optimum water content or the percentage of moisture necessary to give maximum permeability and maximum green bond strength. It has always been our practice to keep our moisture limits as low as possible. Elasticity or brittleness of the sand must be considered also. As all the sand used in our systems is synthetically bonded or "tailor made," the rapidity with which the sand dries out must be noted. There is one other factor that should be mentioned again which plays an important part in the selection of the moisture content. This is the amount of fuel oil in the sand. Since the practice of using fuel oil in the sand was started, we have been enabled to lower the moisture content 0.5 per cent.

37. Proper moisture control helps to eliminate foundry losses due to blows, drops, scabs, cuts, rough casting surface, and dirt. Moisture can be called the most potent variable.

Bond Control

38. Bond is controlled by the addition of a rebonding mixture. Three kinds of bonding material are available, natural bonded sands, fire or flint base clays, and bentonites. Raw clays and bentonites should not be used, as segregation will take place.

39. A mixture of clay or bentonite and burned sand mixed thoroughly in a sand mill gives a very satisfactory rebonding mixture. The moisture content of this mixture must be held low to prevent balling up. Even with this precaution, some segregation will be noticeable.

40. This mixture is stored in small hoppers, from which a

continuous stream is run onto the elevating belt. This mixture then passes into the pug mill and on through the revivifier which breaks up any lumps or balls of sand formed in the pug mill.

41. The amount of rebonding mixture to be added is dependent upon:

- (1) Desired green strength.
- (2) Grain fineness.
- (3) Weight of castings.
- (4) Temperature of metal.
- (5) Length of time castings remain in sand.
- (6) Mixing conditions.

42. The amount and strength of the rebonding mixture to be added is determined through the laboratory strength tests. A tensile strength apparatus which records grams per square centimeter is used for this purpose.

43. Fig. 5 gives a running record of the strength control for a single shift on sand systems No. 1 and 2. On system No. 1 the tensile range is 60 to 70 grams per sq. cm. On system No. 2 the tensile range is from 30 to 33 grams per sq. cm. A 32 gram tensile strength on this machine is equivalent to about 6.5 lb. compression or 1.35 lb. shear. A 65 gram tensile strength is equivalent to about 11.4 lb. green compression or 2.3 lb. shear.

44. The actual percentage of clay in both of these systems is about the same or about 13 per cent. The great difference in green strength between the two systems is due primarily to the difference

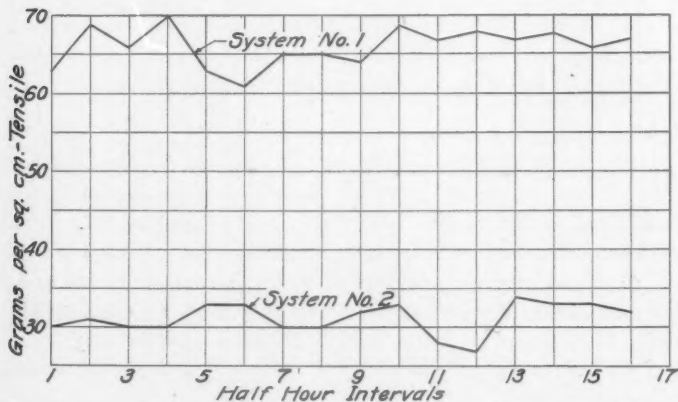


FIG. 5—RECORD OF TENSILE STRENGTH OF TWO SYSTEM SANDS OVER A SINGLE SHIFT PERIOD.

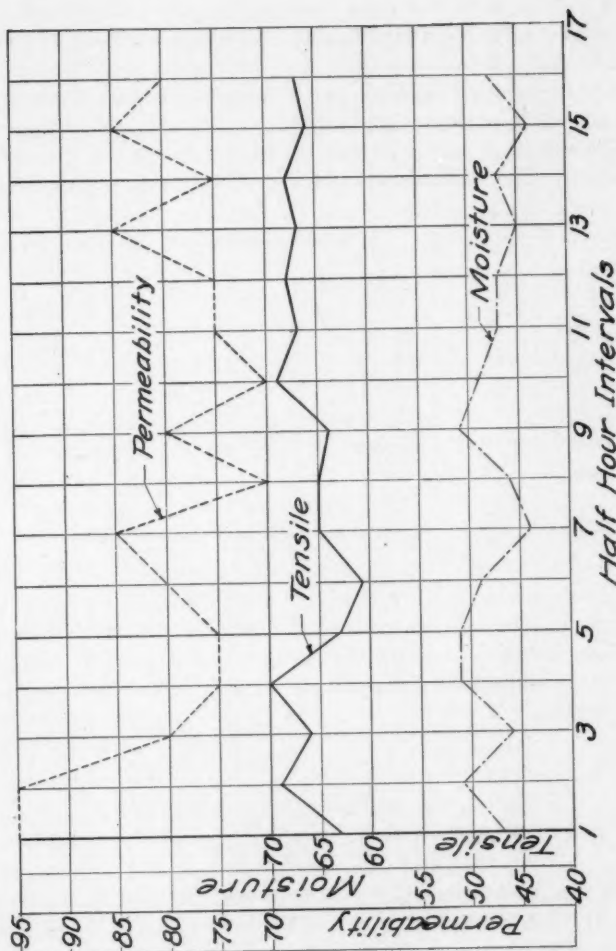


FIG. 6—MOISTURE, TENSILE STRENGTH AND PERMEABILITY CONTROL OF SAND IN SYSTEM NO. 1 OVER A SINGLE SHIFT PERIOD.

in A.F.A. Fineness. As stated before, one system uses an A.F.A. Fineness of 55, the other one of 70.

45. The dry bond strength of both of these sands is about 73.0 lb. Good control of bond strength helps to reduce foundry losses caused by blows, drops, scabs, cuts, rough surfaced castings and dirt.

46. Figs. 6 and 7 give an idea of how sand systems No. 1 and No. 2 run in regard to control of permeability, tensile strength, and moisture. As was noted before, the results on No. 2 system are more uniform. This is due principally to the conditions exist-

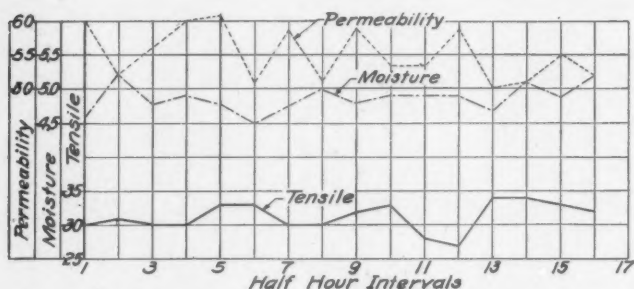


FIG. 7—MOISTURE, TENSILE STRENGTH AND PERMEABILITY CONTROL OF SAND IN SYSTEM NO. 2 OVER A SINGLE SHIFT PERIOD.

ing at the shake-out on No. 1 system. Trouble has been encountered in maintaining a constant amount of core sand at the shake-out. Due to the weight of the castings and the long period they remain in the sand, the latter becomes extremely hot, to the detriment of proper control.

Sea Coal

47. Sea coal can be called a necessary evil in malleable foundries. It is well known that its addition prevents the sand from burning onto the castings. However, it also has a detrimental effect on bond and permeability. Unless used judiciously, sea coal will cause rat-tails, cold-shuts, mis-runs, dirty molding, drops and surface checks.

48. To properly control the amount of sea coal is not easy. This, however, must be done and the amount in any one system must be held fairly constant.

49. The proper selection of a sea coal is dependent upon the

weight of the castings, the amount of casting surface, and the grain fineness of the sand. A low-ash sea coal is always desirable because an excessive amount of ash will increase the amount of fines in the sand, thereby clogging up the heap. The ash must have a high fusion point to prevent any sintering action from that source.

50. For ordinary light work, a sea coal having a high volatile-combustible content and ground so that about 90 per cent will pass through a 200 mesh screen has been found to give very satisfactory results. For heavier work a lower percentage of volatile-combustible matter and coarser material is equally satisfactory.

51. There are four ways of adding sea coal to the sand:

- (1) With rebonding mixture.
- (2) Raw.
- (3) With facing.
- (4) With burned sand at the mill.

52. The first method is not very satisfactory due to the effect on bond and the possibility of the clay and sea coal balling up and causing segregation.

53. Adding sea coal raw is the easiest way, but here again there is the danger of segregation. It must be added uniformly and be thoroughly mixed with the sand. This method has proven to be very satisfactory in our practice. The sea coal is added at the elevating belt from a small storage tank and is mixed in the pug mill and revivifier.

54. The third and fourth methods are the best, as the most uniform results can be obtained. However, the amount of facing used in our practice is too small to maintain the proper percentages of sea coal in the systems. The amount of sea coal to be added is dependent upon:

- (1) Amount of core sand going into the sand.
- (2) Condition of the castings when dumped.
- (3) Length of time the castings are in contact with the sand.
- (4) Area of casting surface.
- (5) Thickness of various cross sections of castings.
- (6) Metal pouring temperature.
- (7) Permeability of sand.

55. After the desired sea coal content has been found, some method for determining the approximate content is necessary. The total carbon in the sand gives a fair approximation. Though not

an exact measure, it suffices with regular operating conditions. The amount of sea coal used per ton of metal cast also is recorded and held within definite limits.

56. Fig. 8 gives the lb. of sea coal used per ton of metal cast over two periods of one month each. A maximum of 36 lb. and a minimum of 21 lb. of sea coal were used per ton of metal poured. The large variation is due primarily to variations in the type of castings. The sea coal content, or rather total carbon content of

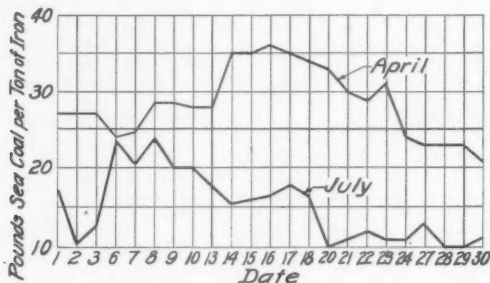


FIG. 8—POUNDS OF SEA COAL USED PER TON OF IRON OVER TWO MONTH PERIODS. CURVE FOR JULY RECORDS SEA COAL USE AFTER PRACTICE OF USING FUEL OIL HAD BEEN STARTED.

the sand, remained quite constant during this period. Generally 25 to 30 lb. of sea coal per ton of iron is considered quite sufficient.

57. Regardless of what kind or how much sea coal is used, the final check is the appearance of the castings.

Use of Fuel Oil in Sands

58. Fuel oil is being used in sands and facings with a marked degree of success. The greatest objections to its use is the amount of smoke produced. The oil is being added to the system sands at the pug mills at the rate of 5 to 10 gal. per hr. dependent upon the tonnage of iron. Since this practice was started, the lb. of sea coal per ton of iron poured has been substantially reduced. Fig. 8 (curve for July) gives the lb. of sea coal per ton of iron poured after the practice of using fuel oil had been started. The average amount of sea coal used has been reduced to 15 to 20 lb. per ton of iron poured. This is a reduction of about 30 per cent of the amount of sea coal used.

59. As was noted before, through the use of fuel oil, the moisture content of the sand can be reduced which also means the

amount of inactive bond in the sand can be decreased. Fuel oil also helps to reduce the stickiness of the sand.

Facings

60. In general, sands in the systems are prepared so that the use of facing can be eliminated. This does not work out in every case. The sand in any one system is prepared to satisfy the majority of the jobs being run on that system. This sometimes necessitates the use of facing on some of the jobs. In some cases, the sea coal content of the system-sand is too high or too low. In other cases, the system sand may be a little too coarse or too fine or, in still other cases, the bond may be a little too low for several of the jobs. To meet these conditions, facing is used.

61. These facings are mixed in a muller type mixer. In the preparation of these facings about 15 per cent of new sand is used. This is the only place, outside of the core room, where any new sand is used.

62. Any one of the three new sands mentioned previously can be used in the preparation of the facings. The amounts of bond, sea coal, new sand and oil are varied to meet the specifications desired. All additions are measured carefully to eliminate variations. The only variable is the refuse sand. Tests are run on facings on every series of batches. So little facing is used that this can be handled easily.

CONTROL OF CORE SANDS

63. Accurate practical control of core sands has always been a rather difficult task. In the control of any core sand, certain factors must be kept in mind:

- (1) Baking temperature.
- (2) Baking cycle.
- (3) Atmosphere of oven.
- (4) Load of oven.
- (5) Method of making core.
 - (a) Blowing machine.
 - (b) Bench.
 - (c) Rollover hand jolt.
- (6) Amount of handling of baked cores.
- (7) Use in foundry.

- (8) Type of foundry sand the core will be used with.
- (9) Metal thickness surrounding core.
- (10) Resistance to metal penetration.

64. There must be complete cooperation between the core room and the foundry so that the cores produced will perform the service required from them.

Fineness

65. The control of fineness in the core sand should be governed, when possible, by the fineness desired in the foundry sands. With clean new sands and complete records of the fineness of the various new sands, the control of fineness depends upon the proper proportioning of the new sands.

66. The desired fineness may, however, be unsuited to a given core, causing metal penetrations or blows. These conditions must

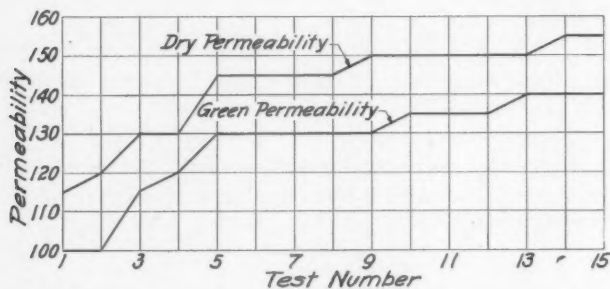


FIG. 9—RELATION BETWEEN DRY AND GREEN STRENGTH ON A GIVEN CORE MIXTURE.

be taken care of first. Too fine a core sand will also raise the oil proportion in the sand and cause poor results on the blowing machines. Too coarse a core sand usually results in an excessive amount of sagging unless the green bond is exceptionally high.

Green Permeability

67. The control of green permeability is dependent upon:
- (1) Fineness of sand.
 - (2) Amount of green bond.
 - (3) Type of green bond.
 - (4) Moisture content.
 - (5) Core oil content.

68. Green permeability tests are run in preference to dry permeability because it requires less time. In any one core sand mixture, there is a direct relation between dry and green permeability. Fig. 9 clearly illustrates this relation. The tests on this core sand mixture show a minimum of 10 and a maximum of 20 (cu. cm. per min.) variation between the green and dry permeabilities. This gives an average difference between the green and dry permeabilities of 15 (cu. cm. per min.).

Moisture

69. The following factors determine to a large extent the amount of moisture necessary in a given core mixture:

- (1) Fineness of core sand.
 - (2) Type of green bond.
 - (3) Amount of green bond.
 - (4) Method of making core.
 - (5) Type of dry bond.
 - (6) Amount of dry bond.
70. All core sands are dried before being used. The sand,

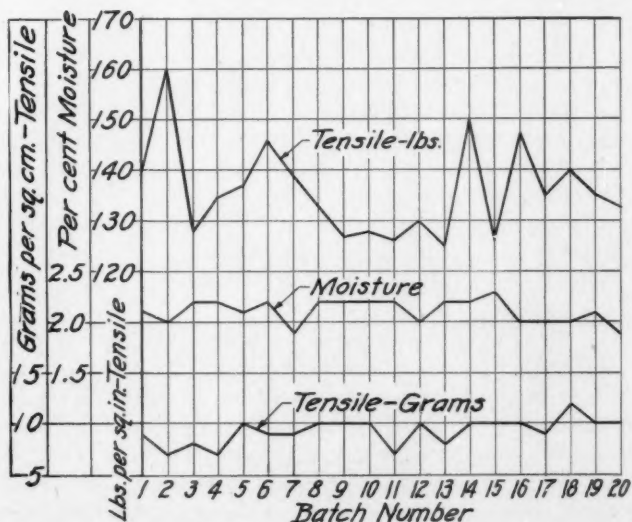


FIG. 10—MOISTURE CONTENT, GREEN TENSILE STRENGTH (IN GRAMS) AND DRY BOND TENSILE STRENGTH (IN POUNDS) OF 20 DIFFERENT BATCHES OF CORE SAND MIXTURE No. 1.

moisture and other ingredients are all measured. These practices permit almost absolute control of moisture content.

71. Fig. 10 gives the moisture content of twenty different batches of the same core sand mixture. The average on this mixture is about 2.3 per cent moisture. A higher moisture content would be desirable from the standpoint of dry bond. In fact, on this mixture a moisture content of 3.0 per cent gives much better dry bond results, but so high a moisture content caused the sand to stick in the core box. In the core room, the tendency is to run the sand too dry which is just the opposite of the tendency of the foundry.

Green Bond Strengths

72. Green bond strengths are of value only during the baking process or before any dry bond strength has been developed. Green bond helps the core to retain its shape without sagging or collapsing in the baking process.

73. Listed below are some of the factors to be considered in the control of green bond:

- (1) Fineness of sand.
- (2) Amount of cereal binder.
- (3) Amount of clay bond.
- (4) Type of new sand.
- (5) Moisture content.
- (6) Type of driers.

74. As in foundry sand practice, the finer the sand the more clay or cereal binder required to obtain the proper green bond. All the sands used in our practice are practically free from clay so this factor need not be considered. Maximum green bond will be developed at the optimum moisture content. Driers which give full support to the core and can hold the core rigid in the green state are desirable.

75. The production required on some jobs does not permit the construction of driers, due to the cost. Cores made without any driers usually require more green bond strength. Some green bond strength is obtained through surface tension, hence some cores can be made without any addition of cereal or clay bond. Fig. 10 shows the green bond strength of 20 batches of core mixture No. 1. Strengths are given in grams tensile strength per sq. cm. The desired green tensile strength on this mixture is 8 to 10 grams per sq. cm.

Dry Bond Strength

76. Good control of dry bond is much more difficult due to the greater number of variables involved. Beside those listed under green bond control, the following have to be controlled:

- (1) Temperature of oven.
- (2) Baking cycle.
- (3) Atmosphere of oven.
- (4) Thickness of core.
- (5) Volume of core sand being baked.

77. In selecting the proper dry bond, the amount of handling after the core has been baked must be considered first. This gives the basis for determining the necessary minimum dry bond strength. The maximum dry bond strength will vary with the requirements of the core in the foundry.

78. *Baking Control:* The vertical ovens in use, have pyrometric temperature control and the cycles are varied according to thickness and density of the cores being baked. The amount of oil in the cores also affects the baking cycle. The cycle also is varied to meet the load in the oven. The proper baking of cores is of the utmost importance in maintaining uniformity and in aiding in the elimination of foundry losses.

79. Some dry bond strength is obtained from the cereal binder. The finer the sand, the greater surface area of the sand grains in a given volume. Therefore, a fine sand will require relatively more oil to cover this increased surface area. The same holds true in regard to the use of clay bond.

80. Dry bond does not show whether a core will be entirely suitable for a given casting. It does, however, serve as an indication. Other factors which must be considered are collapsibility, hardness and the resistance to cutting and metal penetration. Hardness can be tested but the other three must be controlled mainly through a thorough knowledge of the properties of the raw materials and by observation.

Variation in Control

81. Fig. 10 gives a rough idea of the control of dry bond on one core sand mixture. The figures for this curve are taken from 20 consecutive batches of this mixture. These core test specimens were baked in the vertical ovens. The results are average on 15

cores each. More uniform results could have been obtained by baking the cores in a laboratory oven, but by doing this the variables obtained in baking under operating conditions are lost.

82. Fig. 11 shows the control on core sand mixture No. 2. In this mixture, one more variable is introduced. About 22.5 per cent scrap core sand is used. On this core mixture, a minimum dry bond of 125 lb. per sq. in. is required. There is no maximum limit. A minimum green permeability of 100 is necessary. With a mixture such as this where the limits can be quite flexible or no maximum limit is essential, scrap core sand can be used very efficiently. The results recorded in Fig. 11 were taken from 20 consecutive days operation.

Variation in Mixtures

83. The various core sand mixtures used vary quite a little depending upon the requirements. Dry bonds will run from 100 lb. per sq. in. tensile strength for the weakest mixture to 380 lb. per sq. in. tensile strength for the strongest mixture. Green per-

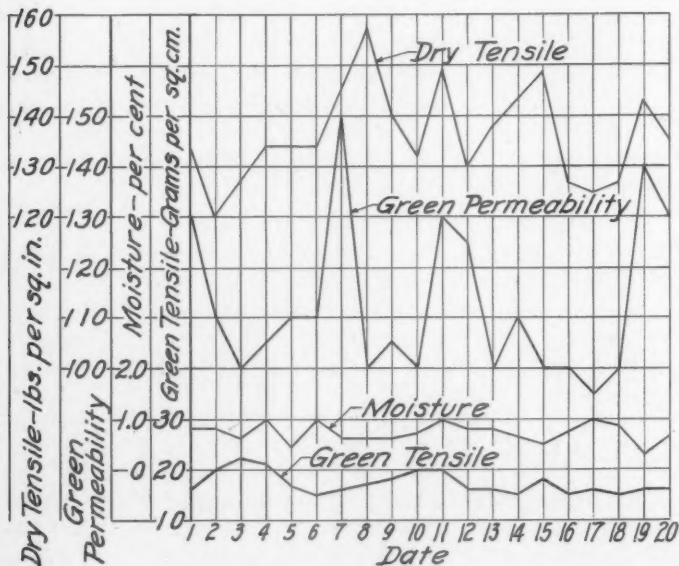


FIG. 11.—CONTROL DATA OF CORE MIXTURE NO. 2, FOR 20 CONSECUTIVE DAYS.

meabilities will run from 60 c. c. per minute for the densest mixture to 360 c. c. per minute for the openest mixture. Green bond will vary from 6 to 30 grams per sq. cm. tensile strength. Moisture content varies from 1.8 to 4.4 per cent. From the range of the variables it can be readily seen why good core sand control is an absolute necessity for efficient core room operation.

84. Some cores must have washes of some sort applied, either in the dry or green state, for the purpose of improving the finish or to stop cutting of the metal. In some cases, pitch is added directly to the core sand mixture for the same purpose. Adding pitch directly to the sand mixture is the cheapest way to take care of these conditions, but unfortunately the results do not always prove satisfactory. Such a small percentage of cores require the application of a wash that very little attention is required to get consistent results. A wash is used on a core only as a last resort.

CONCLUSION

85. With the increasingly greater demand for better castings and the increasing number of centrally located sand systems, sand control in any foundry has become an absolute necessity. The accuracy of sand control is dependent to a large degree upon the sand handling equipment incorporated in these systems. The amount of sand control necessary is dependent upon the variety of the work in the foundry. Sand control begins in the core room and not in the foundry.

DISCUSSION

MEMBER: What per cent of sand does that amount to in the pug mills?

MR. ZIRZOW: Five or six gallons per hour. We run over 75 tons of sand per hour.

MEMBER: Did you find any difference in the permeability after adding your fuel oil to your sand mix? Did the permeability of your sand drop?

MR. ZIRZOW: No, it did not, because at the same time that we add fuel oil we drop our moisture content. Our permeability actually goes up. When you run one per cent over your optimum water content, you have a certain percentage of inactive clay and by lowering that about 0.5 per cent you approach more nearly your optimum water content, which gives you maximum permeability.

MEMBER: You lowered your clay and your moisture at the same time?

MR. ZIRZOW: Yes.

MEMBER: What effect did fuel oil have on your work? Did it improve your surface conditions?

MR. ZIRZOW: If you use an excessive amount of all you will run into cold shuts. We merely tried to maintain the same type of surface we had before. The sea coal content was lowered as the oil was added. If we had maintained that same ratio, I believe it would have improved the surface.

MEMBER: I would like to know what method you employ for removing the fines in this system.

MR. ZIRZOW: We make no effort at all to remove fines from our system. We watch our fines rather closely in our new sand coming in and there is some removed on the top of our screening belt as we screen our sand before it goes into the big 75 ton hopper. Some flows off into the air and a lot is carried over on to the surface of the casting. We have been quite fortunate in maintaining a rather constant fines control, but we have no method of removing fines at all. The breaking down of the sand is not enough to give any trouble.

MEMBER: What effect, if any, does fuel oil have on flowability of your sand? It reduced your moisture percentage,—which of course helped your flowability.

MR. ZIRZOW: I think due to the reduced moisture content and reduced clay content you get a better flowability in your sand. It is especially adaptable where you have a rather flat surface and you are getting scabs.

Some Experiences With Wear Testing

By PAUL S. LANE*, BALTIMORE, MD.

Abstract

Wear testing of materials has been carried on for many years and in many cases with small results. Difficulty has been encountered in securing test data that coincide with service results. In fact, a great difficulty has been duplicate test results on the same specimen. The author describes the apparatus and results obtained in wear testing as carried out by his company since 1934. The paper is divided into four parts, the first of which is devoted to a description of the apparatus used to conduct the tests. He points out that for the product his company is interested in, the apparatus described give results that can be duplicated with reasonable accuracy and at the same time give a fair estimate of what can be expected in service. The second part of the paper deals with some examples of good and poor-wearing irons for use in steam service. In this section, the author gives analyses, relative wear figures, micrographs and hardness data. He describes a metal that has given good service under the conditions stated and also discusses the effect of heat treatment on rings which contain approximately 1.25 per cent nickel and 0.40 per cent chromium. The third part deals with experiments in wear resistance for rings used in automobile and airplane motors. The final section describes the results obtained with bronze rings and with rings made of a combination of bronze and cast iron. The paper ends with a discussion of some of the "impressions" the author received during the course of his investigation of wear resistance. He discusses the effect of structure on wear, effect of grain size, section, and the various elements.

Introduction

1. A method for measuring or indicating the relative "wear" of metals presents many problems, since wear is apparently a very

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important but, at the same time, elusive quality. Particularly is this true of so complex a material as gray cast iron. Those who have followed attempts in the past 10 years to evaluate this quality in gray cast irons, realize that rather disappointingly little success has been had. We have been unable to predict or duplicate service results, and obtaining check results, under various forms of laboratory testing, has been difficult. It is the purpose of this paper to describe a type of wear test which has been surprisingly useful, and which, to a large degree, ties in with actual service performances. An effort is also made to illustrate certain characteristics of "good" and "poor" wearing irons, and to touch briefly on a relatively new application of "combination" materials.

2. Without in any sense losing sight of the importance of prior attempts in this phase of investigation, but rather for the sake of brevity, no bibliography will be given. Boegehold, in his paper¹ on wear tests, lists a most complete summary of papers related to this subject.

THE WEAR TESTING MACHINE AND ITS OPERATION

3. Fig. 1 shows the testing apparatus in plan and elevation. The machine is the "brake shoe test" type consisting of an ordinary $\frac{1}{4}$ h.p., motor running at 1425 r.p.m. and having a somewhat extended shaft to accommodate two rings or drums on right and left-hand side. The drum fixture, or hub, is of aluminum, accurately machined on the motor shaft to a diameter of 3.1875 in. Solid rings or drums are cast and machined to fit snugly over these hubs. The drums are $3\frac{1}{2}$ in. outside diameter and 3.1875 in. inside diameter and have a total face width of $1\frac{1}{4}$ in., or four drums of $\frac{5}{16}$ in. face-width may be used.

4. The usual test set-up considers these drums as representing the cylinder, or bearing surface, against which the piece in question, representing the piston ring or other rubbing part, is tested. In the event that test specimens are cut from cylinder sections or other castings where one cannot obtain rings or drums, the procedure is often reversed so that the revolving drum is considered as the piston ring and the "specimen" as the cylinder. Mounted in front of each of these drums is an adjustable bracket upon which is held the lever arm, pivoted in small ball bearings,

¹ Boegehold, A. L., "Wear Tests and the Value of Hardness Testing for Control of Product," TRANSACTIONS, American Foundrymen's Association, Vol. 41, (1933), pp. 573-586. See also Bimonthly Trans. A.F.A., April, 1934, pp. 585-586.

and carrying the load or weights, which are suspended therefrom by means of rubber tubing.

5. The specimen is clamped in the holding fixture as shown. This fixture is a collar, accurately fitted on the lever arm, and adjustable by turning through a short arc, so as to permit locating the specimen flat or parallel with the drum face. The specimen is locked or held in this position by a set screw.

6. The specimens are machined to $\frac{1}{2}$ in. square and to any desired width up to $\frac{5}{16}$ in., though in most of the tests, we have used a width of 0.286 in.

7. After the specimen is tightly clamped in the holding fixture, the lever arms are adjusted by the adjustable posts so that

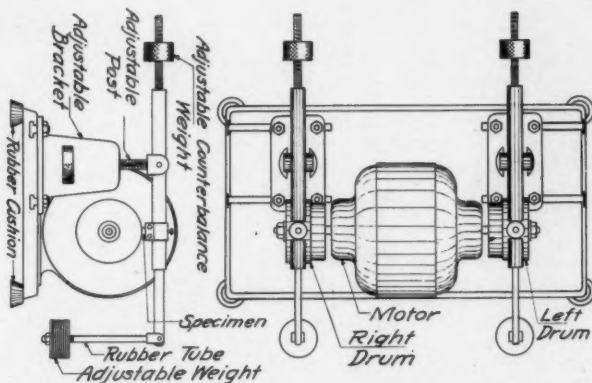


FIG. 1—SKETCH OF WEAR TESTING MACHINE.

they are level, and in such position that the specimen makes "line contact" at its center with the drum. It is to be noted that the brackets are constructed so as to allow lateral and vertical movement of arm which permits locating the specimens centrally and in any desired location on the drum. The entire unit is mounted on rubber supports.

Wear Test Machine Operating Data

8. The drum is $3\frac{1}{2}$ in. O.D. \times $3\frac{3}{16}$ in. I.D. \times $1\frac{1}{4}$ in. wide. It is normally made of gray cast iron of average cylinder hardness, or may be of steel, bronze, etc. A fine turned finish is normally used (120 feed) on drums representing the average cylinder. When drums of hardened cast iron or nitrided steel are used, these

are finished by grinding. Drums are first cleaned by slushing in solvent Naphtha No. 12, and dried with cheesecloth to remove excess dirt and grease. They are then mounted on the test machine and while running, further cleaned with the Naphtha No. 12, using paper toweling until no discoloration is had on a clean towel. A one in. square piece of No. 0 French emery paper is held against the cleaned surface for one minute, followed by another cleaning with Naphtha, followed by wiping with cheesecloth to remove paper fibres. The drums then are ready for use. Drums are prepared immediately before use to preclude chances of rusting, etc.

9. The specimen the author has used is 0.500 in. \times 0.500 in. \times 0.100 in. to 0.286 in. with a ground finish. At start of test, the specimen makes only line contact with drum, unit pressure decreasing as wear occurs. Some fixed conditions of the tests are:

Speed—1425 r.p.m.—1305 ft. per min.

Test Duration—60 min.

Total Load—2 to 5 lb.

Lubrication—Dry.

Procedure

10. Generally two different irons are tested, four runs each, alternating from right to left-hand drum. "Wear" is determined by weight loss of specimen and of drum, if desired.

METHOD OF TESTING

11. The testing unit is adapted for "dry" wear testing only. Two specimens are run at the same time, one on the right and one on the left-hand side. These specimens may be of the same material, or one may be a sample of known value of performance, in which case the machine acts as a "comparator" and tells the relative wear resistance of the unknown specimen. With wide-face drums (1 $\frac{1}{4}$ in.) the first "run" is made on the outer track on both sides of the machine. The total load is 5 lb., though this may also be varied to suit. Time of run is normally 60 minutes.

12. In spite of the extreme simplicity of this unit, it is seen that (a) size of specimen, (b) load on specimen, (c) type and hardness of contacting surface, (d) speed and duration of test, may all be varied quite readily to suit the material in question, or to simulate, to a certain degree, the loads and speeds likely to be encountered in service by the particular metal being tested.

How Wear Is Determined

13. "Wear" is determined by weight loss of specimen, and may be further checked by measurement of the width of the worn area by means of an ordinary Brinell microscope. Using the usual type of square specimens, four runs may be made on each specimen, one on each of the four sides. To equalize any slight differences between the right and left-hand side of the machine, specimens are alternated side to side. Four one-hour runs serve to give a good idea of probable wear resistance of the specimens, which, however, may be refinished and additional determinations made on the same test piece. By means of a special holding fixture, sections or segments of automotive or aircraft piston rings may be used as specimens.

14. Each drum, using the usual size specimen, will permit three or four separate runs or determinations after which they may be removed for examination and a new set of drums installed. In our method, a new "track" or drum, is used for each run. Since these drums may be cast by the multiple molding process and a great many of them poured from a single ladle or heat, a potent variable is thereby eliminated.

15. Another important feature of the test is that, at the start, specimens make only "line contact" with drum, and high unit pressures exist, which gradually decrease as more and more area of contact is made. This follows, to a large degree, the "seating in" or "wearing in" process in a sleeve or bearing, and has been found in practice to largely determine subsequent life. Hence, it is seen, that those specimens which wear away rapidly, soon increase their total area in contact with the revolving drum, with a corresponding decrease in unit pressure. A better wearing iron will then operate, during the test, at a correspondingly higher unit pressure. Example:

	"Wear" Wt. Loss	Area at Finish	Unit Pressure
Iron	Mgs.	Sq. In.	Lbs. per Sq. In.
A—good	11.6	0.054	92.0
B—poor	31.9	0.080	62.5

16. In the above example, 5 lb. total load was used on specimens of 0.286 in. x 0.500 in. The curvature of the worn area has not been taken into consideration, since this involves considerable calculation, and is not of use where wear is determined by the "weight loss" method.

17. At the present writing, it appears that a test duration of

one hour gives most consistent results. Though some tests have been run for longer periods, there is indication that, due to formation of "film" and oxidation products, on both drum and specimen, more erratic values are obtained. Specimen temperature, at the end of one hour's running, averages around 270° F.

DISCUSSION OF TESTS

18. After four one-hour runs on this machine, examination of the specimen offers the following data of interest:

- (1) Relative "Wear Value" in milligrams weight loss.
Determined by weighing specimen on chemical balance.

- (2) Tendency of material to develop "glaze" or "polish".
Examination of the worn areas under the microscope gives a fair indication of tendency of material in question to work harden or "glaze", believed so desirable in many cases, such as on cylinder wall, rings, etc.

- (3) Ability of metal to self lubricate; also "scoring" tendencies.

Some irons, under test, powder rapidly and throw off appreciable quantities of carbon dust. Others develop a "knotty" appearance somewhat "pitted," similar to an antimony-babbitt structure. This is indicative of good wear resistance being usually accompanied by low "weight loss" or "wear values". Others distinctly "score" and "seize" resulting in a scratchy appearance. A feature of the machine is that the effect of the various irons, upon the drums or "cylinder" is readily seen, since a newly machined surface or track is used for each test. An iron which shows low wear values, due to inherent high hardness, and which would be unsuited for bearing usage, due to its disastrous action on the contacting surface, is readily recognized by its effect on the drum track.

- (4) Tendency of material to "lip" or "feather".
This is indicated by presence of "wire" edge on either side of the specimen, and while not of particular interest in the case of relatively brittle materials, such as cast iron, it is of value in testing the more

ductile alloys, wherein this tendency might be a determining factor under service conditions.

19. Thus, it is apparent that much pertinent data may be obtained with this method of testing, and at little expense in preparation of specimens, since if desired, by refinishing both drums and test piece, further use may be made of same. Specimens are small. They may be obtained from very light sections or samples, or may be machined from relatively heavy bars or castings, thus allowing study of changes in wear resistance in relation to mass effects, cooling rates, etc.

20. The fact that the same specimen surface, used in determining "wear", adapts itself readily for preparation for microscopic examination of structural features also is helpful. Of interest is the fact that slight differences in the finish of the specimen seem not to alter the wear values appreciably, due, no doubt, to the manner in which the contact is gradually made with the drum. An ordinary tool room grinding job in finishing the specimens works satisfactorily.

21. This apparatus was designed several years ago, and has been used continuously since January, 1934, during which period only very minor changes have been made. Thus, we have now had two years of more or less continuous research regarding wear of metals, and we know of no phase of investigation which has been so fruitful. Metals entering our laboratory for examination, beside undergoing the usual chemical, microscopic, and physical examination, also regularly are tested for "wear", and given an arbitrary rating as regards this faculty.

SOURCE AND HISTORY OF SPECIMENS

22. Most valuable in a wear research program is procuring specimens of known service performance, both good and bad. These act as "bench marks" for establishment of values upon which to base, and properly interpret, further wear ratings. To obtain these, however, is not so simple as might at first be supposed, because local conditions of usage often more than overshadow the existing range between a good and poor wearing iron. Much care must be exercised in this respect, since one may readily obtain a "good" wear test value, only to find that actual service life was very poor, the reverse also being true.

23. Design or type adds another variable. With reasonable care, and what is equally important, good customer cooperation,

good and poor wearing metals may be obtained from a wide and varied field of service, and with a workable degree of dependability.

24. Obviously, when comparing specimens from these different classes of service, it does not necessarily follow that the better wearing specimen is suitable for use in a type of service wholly different from that in which it performed so well. For instance, a "good wearing" iron for superheated steam use, and having a section size of $1\frac{1}{2}$ in. would not likely be "good wearing" in say, for instance, an aeroplane engine ring of $3/32$ in. section.

25. Naturally, most of our experience is related to irons for use in piston rings, but since rings are supplied from $3/8$ to 120 in. in diameter, and for all fields of service, it is believed that these same findings will, in the main, apply to most general cases where gray cast iron is used for bearing work.

26. Moreover, our experience covers applications where lubrication is abundant and controlled to a nicety, as well as those where practically "dry" operation is had, embracing, what might be considered the "usual case", where, for many reasons, evidently beyond control, dry periods of varying duration, exist.

Part 1

LARGE RINGS IN STEAM SERVICE—SOME EXAMPLES OF "GOOD" AND "POOR" WEARING IRONS

27. To illustrate the method of application of this means of testing and the results therefrom, several examples will be given, many of which are taken from reports in our files, following which an attempt will be made to point out the salient features of the two types of materials. Most of these examples, where service records are included, are from fields where what would be classed as "poor" lubricating conditions exist, rather than from applications operating under "good" lubrication. This is done because the former better illustrates the wide differences possible in wearing qualities, and also because more data of this type has been developed.

28. The irons discussed in the immediately succeeding section of this paper have been used as piston rings, from both our own and other manufacturers' production. The sections involved run from $3/8$ to $1\frac{1}{2}$ in. with diameters of 6 to 36 in. These sizes find general use in air and ammonia compressors, saturated and

superheated steam, marine, stationary and railroad, and in some cases in the larger heavy-duty Diesels. An arbitrary wear test "rating" is given as shown in Table 1, this having been set up and used for comparison under our "standard" test methods.

Table 1
MGS. WEIGHT LOSS—ONE HOUR

Excellent	18
Good	20-24
Fair	26-30
Poor	Over 30

29. The above range covers the spread encountered in most piston ring materials though it does not, of course, cover the extremes in either case. Some irons have shown wear values of 10 mgs. or less; others run up to 100 mgs. weight loss under the same test conditions. The poorer wearing irons result in greater differences in check determinations. Since they wear faster, relatively slight differences in structure become magnified.

30. It possibly also will be of interest to study the analysis of irons in each group and for this reason, typical examples are shown in Table 3.

Example "A"—Preliminary Study of Two Irons—No Service Record

Table 2
PROPERTIES OF TWO IRONS TESTED

	Iron E-22	Iron E-24
Silicon, per cent.....	1.75	2.00
Sulphur, per cent.....	0.103	0.070
Phosphorus, per cent.....	0.38	0.32
Manganese, per cent.....	0.62	0.58
Total Carbon, per cent.....	3.63	3.26
Chromium, per cent.....	—	0.47
Brinell No.....	217	145
Section in inches.....	$\frac{3}{4}$	$1\frac{1}{2}$
Wear Value, mgs.....	29.5	15.9

31. The data for the irons of this example are given in Table 2. Fig. 2 illustrates the structural features of these two widely different irons. One run from this test was purposely stopped after only 15 minutes running time, the contacting surfaces cleaned with alcohol and photographed at 50 diameters, with the results shown in Fig. 3. Comments taken from this report follow:

Table 3
ANALYSES OF IRONS POSSESSING DIFFERENT WEARING PROPERTIES

Spec. No.	Wt. Loss "Wear" Mgs.	Brinell No.	Si.	T.C.	G.C.	Analysis—Per Cent			Mn.	Ni.	Cr.
<i>"Excellent" and "Good" Wearing Irons</i>											
23	10.4	207	1.55	3.15	2.38	0.77	0.13	0.17	1.07	0.82	0.38
31	16.8	195	1.41	3.20	2.34	0.86	0.128	0.16	0.85	0.97	0.36
19	19.7	229	1.90	3.22	2.41	0.81	0.115	0.30	0.70	1.10	0.55
3	20.0	220	1.56	2.83	1.97	0.86	0.15	0.12	0.38	—	0.34
17	20.9	190	1.45	3.52	—	—	0.095	0.36	0.61	1.26	0.36
1	21.1	152	1.60	2.92	2.49	0.43	0.12	0.32	0.70	0.07	0.12
12	22.8	217	1.61	3.50	2.78	0.72	0.066	0.43	0.56	1.45	0.20
18	23.9	152	1.97	3.33	—	—	0.080	0.51	0.58	—	—
<i>"Poor" Wearing Irons</i>											
2	31.0	223	1.85	3.61	2.82	0.79	0.097	0.27	0.67	1.12	0.47
4	32.1	223	1.41	3.46	2.75	0.71	—	0.29	0.79	1.29	0.28
6	35.8	152	1.30	3.21	—	—	0.134	0.25	0.88	—	0.076
11	37.3	156	1.41	3.54	2.87	0.67	0.12	0.40	0.50	—	—
30	39.0	223	1.81	3.31	—	—	—	0.39	—	—	—
8	40.4	180	1.78	3.92	—	—	0.082	0.50	0.54	—	—
9	42.5	170	1.53	3.60	—	—	0.071	0.34	0.58	—	—
29	47.4	214	2.25	3.57	—	—	—	0.36	—	—	—

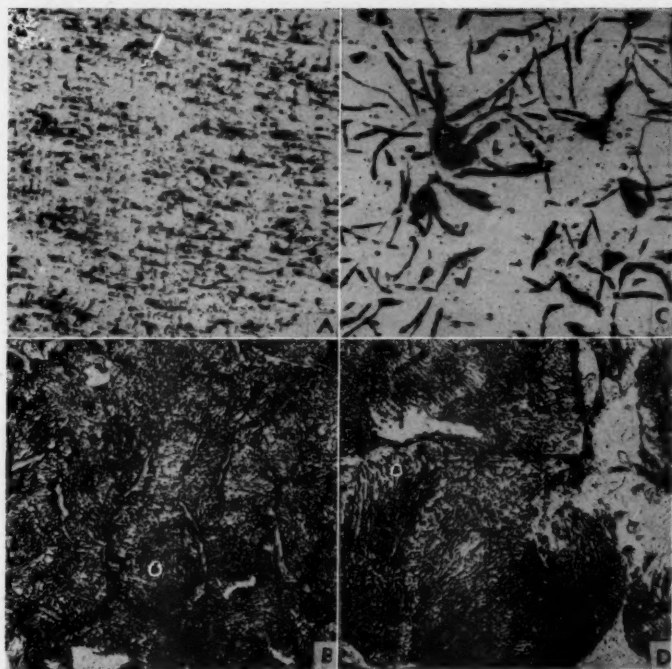


FIG. 2. A—IRON E-22 UNETCHED SHOWING GRAPHITE DISTRIBUTION 50x. B—SAME ETCHED, 500x. C—IRON E-24 UNETCHED, 50x. D—SAME ETCHED, 500x.

“Photomicrographs show comparative structures of a very fine or close grained iron (Fig. 2A and B), and that of a coarse open grained material (Fig. 2C and D). The two upper photos illustrate the difference in graphite form and size. It is believed that there exists an optimum graphite size for best wear resistance for any given section size. Irons with very finely precipitated graphite take a very “snug” fit against the cylinder contacting surface, and being very uniform microscopically, fail to glaze or develop surface films, but tend rather to “powder,” resulting in very rapid wear in the absence of suitable lubrication. In the case of a coarse grained iron with an irregular or heterogeneous structure, though possibly showing lower physical test values, better wear resistance is had. Irons of this type rapidly develop a “glazed” and

"pitted" surface, which seems to retard further wear or abrasion.

"These conditions are illustrated in Fig. 3. Fig. 3A shows the appearance of the surface of the fine grained iron at 50 magnifications after only one-quarter hour of dry running against a highly polished and ground cast iron drum. Note how the whole microscopic surface has taken a bearing against the drum (representing the cylinder in this case), with little or no "high and low" points contacting. Loosened material, being finely divided, and with no tendency to "work harden" or "glaze," rides between the contacting surfaces, and forms an excellent abrasive to further promote wear.

"Fig. 3B illustrates the appearance of the coarse grained iron after the same time of dry operation under identical



FIG. 3. APPEARANCE OF WORN AREAS AFTER 15 MIN. DRY RUNNING. A—IRON E-22. B—IRON E-24. BOTH MICROGRAPHS AT 50X.

conditions. Notice the true "bearing metal" finish, that is, definite irregularity of surface hardness, as shown by the "pitted" effect. The light gray portions in this photo are the points taking the bearing, while the dark areas are the "valleys." A finish of this type, being relatively ductile, continually changes itself through surface movement or "flow," but since inherent irregularity is incorporated in the structure, there always exists this tendency for the harder constituents to take the load, while the softer body of the metal adjusts itself, within certain limits, to changing frictional conditions.

"It is not, of course, always possible to incorporate such a structure in a casting, and yet retain other physical char-

acteristics necessary for its successful operation. Furthermore, under conditions of good lubrication, the "normal" heterogeneity of cast iron, coupled with its unctuous or greasy qualities, permits of successful operation."

Example "B"—Preliminary Study of Two Irons—No Service Record.

Table 4
PROPERTIES OF IRONS 416 AND X16

	Iron 416	Iron X16
Silicon, per cent.....	1.49	1.40
Sulphur, per cent.....	0.084	0.093
Phosphorus, per cent.....	0.38	0.38
Manganese, per cent.....	0.52	0.45
Total Carbon, per cent.....	3.50	3.57
Nickel, per cent.....	—	—
Chromium, per cent.....	—	0.25
Brinell No.	205	190
Section in inches.....	$\frac{3}{4}$	2

Wear Results

Determination No.	Dry Operation—60 Min.	
	Iron 416 Wt Loss in mgs.	Iron X16 Wt. Loss in mgs.
1	36.4	11.5
2	34.6	9.4
3	28.2	12.5
4	26.3	11.6
5	31.0	11.0
6	34.9	14.0
Average—Wt. Loss.....	31.9	11.6
Ratio	2.75	1

32. The wear test values given in Table 4 illustrate about the usual differences in check determinations, and it is apparent that these may be reconciled by an average of four to six separate runs.

33. Fig. 4 illustrates the appearance of these two wear test specimens at end of a run, the width of worn area indicating the degree of wear. The parallel lines seen on the worn area are due to the threaded finish on the drum surfaces. Ground drums do not, of course, exhibit these markings.

34. Note the distinct bearing metal structure or surface on the X16 iron specimen, this being entirely lacking on the 416 iron.

35. Of further interest is the similarity of chemical compo-

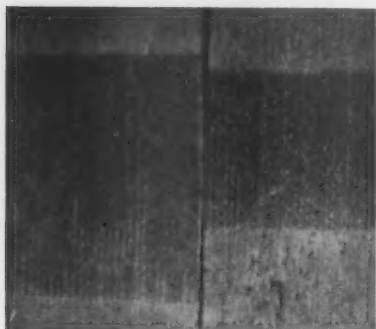


FIG. 4. WEAR TEST SPECIMENS AT 5x. THE DARK AREAS INDICATE THE AMOUNT OF WEAR. LEFT—IRON 416. RIGHT—IRON X16.

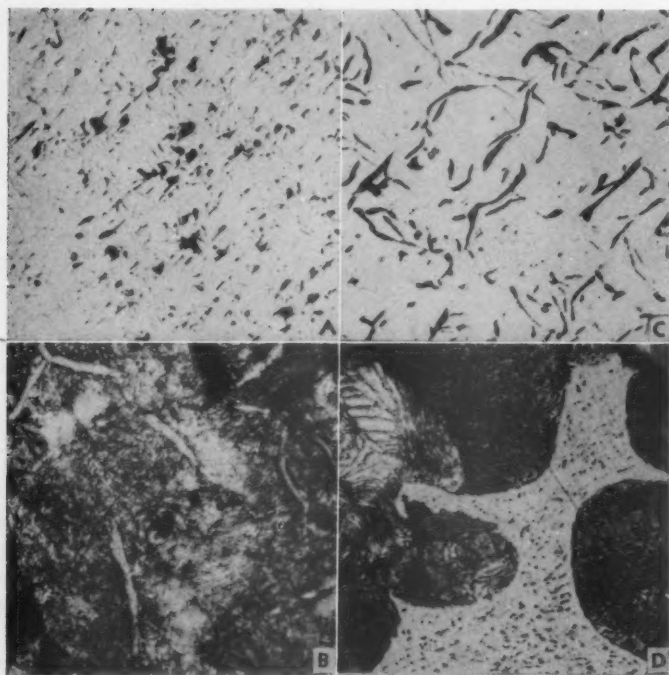


FIG. 5. A—IRON 416 UNETCHED, 50x. B—SAME ETCHED, 500x. C—IRON X16, UNETCHED, 50x. D—SAME ETCHED, 500x.

sition of these two irons associated with the wide difference in structural composition. Appearance of graphite and etched structures is illustrated in Fig. 5.

Example "C"—Check against reported service record. Steam deck winches.

Table 5

PROPERTIES AND PERFORMANCE DATA ON IRONS 415 AND S15

Analysis	Iron 415	Iron S15
Silicon, per cent.....	2.14	1.60
Sulphur, per cent.....	0.087	0.135
Phosphorus, per cent.....	0.42	0.49
Manganese, per cent.....	0.53	0.42
Total Carbon, per cent.....	3.70	3.40
Brinell No.	190	140
Section in inches.....	$\frac{1}{2}$	1
Wear Value—Wt. Loss, mgs.....	94.3	18.3
Ratio	5.1	to 1
Service—months	1	12

36. The analyses and performance data for irons 415 and S15 are given in Table 5. Study of the photomicrographs of these irons (Fig. 6) indicate the following structural features:

	Iron 415	Iron S15
Graphite	Extremely fine—Nodular	Coarse long veins
Matrix or Groundmass....	Pearlite—very fine	Pearlite—very coarse
Grain size.....	Fine—regular	Large—irregular
Steadite	Small—well distributed	Coarse—segregated
Ferrite	Scattered islands	Edges of graphite

37. These two irons illustrate very forcibly, how wide a range of wear resistance is possible in gray cast iron. These two irons were in service on the same vessel under similar conditions. Steam pressure, of only 100 lb. is the general case, but practically "dry" operation is had. Furthermore, one has but to watch the stevedores unloading a freighter, scheduled to put back to sea in a few hours, to realize these machines are far from being "nursed" during operation.

38. Rings were supplied for replacement in these units closely following that of the S15 composition and structure, and at the end of four months were still performing very satisfactorily. The value of a laboratory test which enables a manufacturer to find the answers to such problems is, of course, obvious, particularly so if preliminary or "piloting" data may be had, rather than waiting for "good" or "bad" reports from the field.

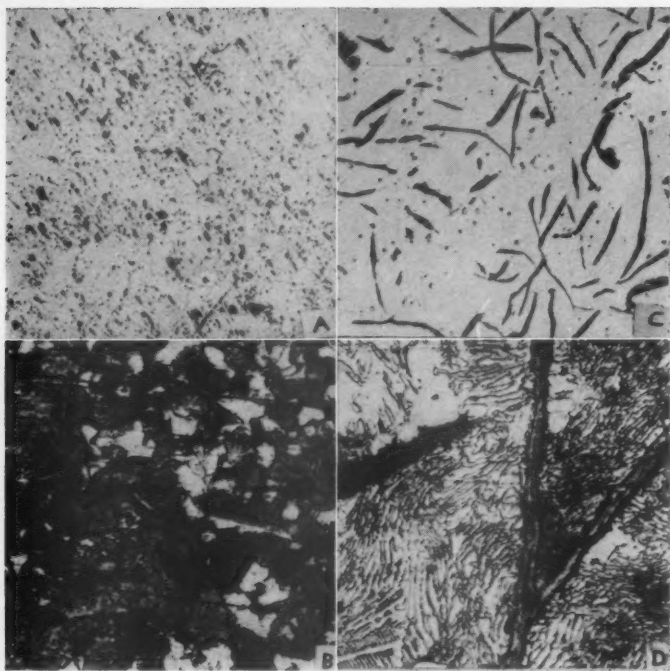


FIG. 6. A—IRON 415 UNETCHED, 50x. B—SAME ETCHED, 500x. C—IRON S15 UNETCHED, 50x. D—SAME ETCHED, 500x.

Example "D"—Check against service record—Superheated steam service.

39. Example D is of irons 2-W and 31-A, used for superheated steam service. The analyses and the performance data for these are given in Table 6. Micro-structures are shown in Fig. 7.

40. These two irons again illustrate the influence of structural makeup on wearing qualities. Under test the 2-W specimen powdered quite rapidly, while the 31A, though of less hardness, took on a glazed and pitted appearance tending to retard further abrasion or wear.

K-6 Metal

41. Figs. 8A and 8B illustrate micrographs of a type of iron (K-6 metal) which has been used for several years and which has given excellent service over a wide field of applications. The

Table 6

ANALYSES AND PERFORMANCE DATA FOR IRONS 2-W AND 31-A

	Iron 2-W	Iron 31-A
Silicon, per cent.....	1.85	1.41
Sulphur, per cent.....	0.097	0.128
Phosphorus, per cent.....	0.27	0.16
Manganese, per cent.....	0.67	0.85
Total Carbon, per cent.....	3.61	3.20
Graphitic, per cent.....	2.82	2.34
Combined, per cent.....	0.79	0.86
Nickel, per cent.....	1.12	0.97
Chromium, per cent.....	0.47	0.36
Brinell No.	223	195
Section in inches.....	$\frac{1}{2}$	$1\frac{1}{2}$
Service—miles	5000	—
Wear Value, mgs.....	30.9	16.8
Ratio	1.83	to 1

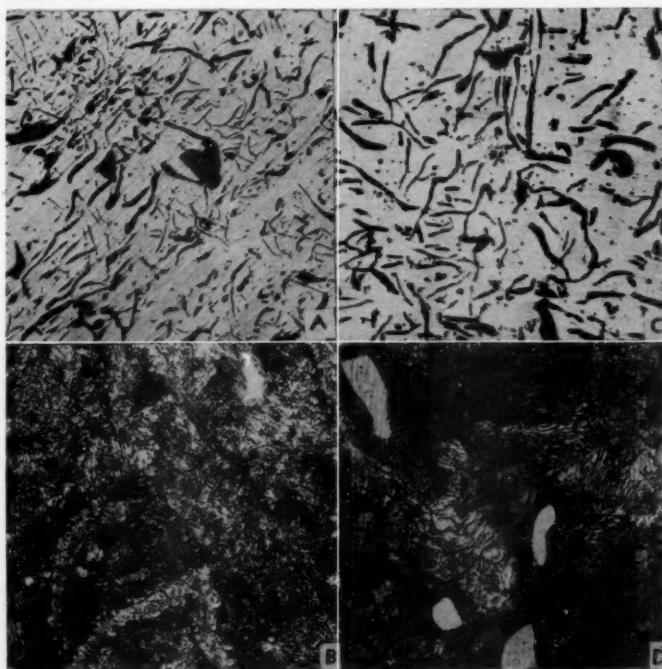


FIG. 7. A—IRON 2W UNETCHED, 50x. B—SAME ETCHED, 500x. C—IRON 31A UNETCHED, 50x. D—SAME ETCHED, 500x.

structure is distinctly heterogeneous and shows numerous steadite islands associated with cementitic forms. This iron contains 1.00 to 1.25 per cent nickel, 0.50 per cent max. chromium, manganese and phosphorus around 0.30 to 0.50 per cent, carbon 3.45 per cent and silicon to suit section. Its wear value runs around 20.0 mgs., and it has good physical and corrosion resisting qualities.

42. Figs. 8C and 8D illustrate a type of iron in contrast to K-6 metal which has definitely very poor wearing qualities. The graphite is present in an extremely fine or "eutectic" form, fracture is "fine grained" and "close." Here the structure is "too uniform" for good bearing properties, and while good performance is sometimes had under conditions of abundant lubrication, dry operation results in rapid "powdering" away of this "fine grained" and "homogeneous" material. Its wear value will always run well over 30.0 mgs. with our method of test.

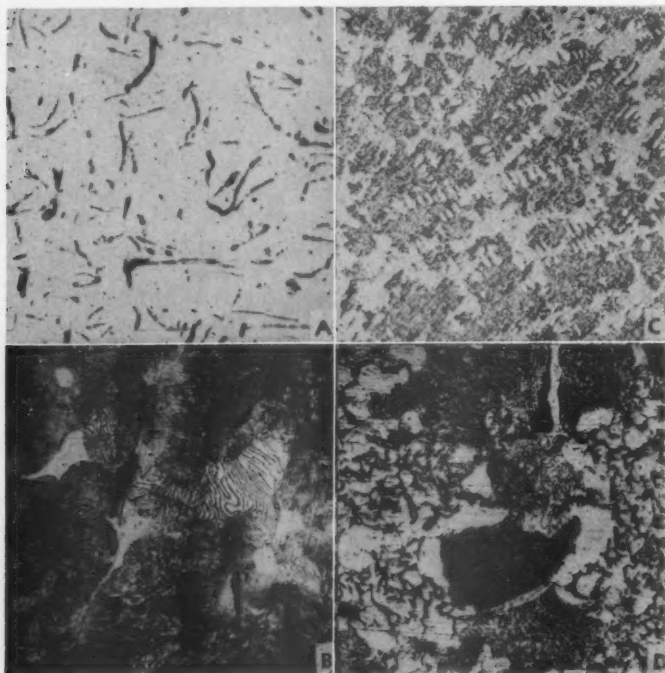


FIG. 8. A—METAL K-6, A GOOD-WEARING STRUCTURE, UNETCHED AT 50X. B—SAME ETCHED, 500X. C—IRON WITH THIS TYPE STRUCTURE IS POOR-WEARING. UN-ETCHED, 50X. D—SAME ETCHED, 500X.

EFFECT OF HEAT TREATMENT ON WEAR

43. The K-6 alloy iron previously mentioned, and shown in Figs. 8A and 8B, was investigated as to the effect of heat-treating on its wear resistance, with the hope of improving this quality thereby. The sections used for this test were $1 \times \frac{7}{8}$ in. as cast, made under normal foundry production methods, and having the following chemical composition:

Analysis	Per Cent
Silicon	1.75
Sulphur	0.12
Phosphorus	0.30
Manganese	0.70
Total Carbon.....	3.35
Nickel	1.25
Chromium	0.40
Brinell No.—as cast.....	195

44. Specimens were heated to 1500° F. for 30 minutes and quenched in oil and then drawn at increasingly higher temperatures. Details are shown in Table 7, and listed in the order of the resultant Brinell Hardness values. Average wear values are also given, along with the wear effect on the drums. These values are plotted in Fig. 9.

Table 7
SPECIMENS QUENCHED IN OIL FROM 1500° F.

Spec.	Draw. °F.	Minutes	Wear-Wt.		Remarks
			Brinell No.	Loss Mgs.	
A	—	—	452	9.7	Distinct Scoring
B	—	—	408	13.8	" "
C	700	10	343	10.3	" "
F	850	30	311	18.8	" "
E	800	30	293	17.1	" "
D	900	30	285	18.4	" "
G	900	30	269	13.1	" "
H	1100	30	230	20.4	" "
M	1100	5 Lead Bath	226	18.3	" "
N	1200	10	226	28.1	Normal
L	1200	30	208	27.9	"
I	1200	30	207	31.3	"
K	1200	10	207	28.5	"
O	*	*	195	25.3	"
J	1100	30 Lead Bath	194	21.2	"

* As cast.

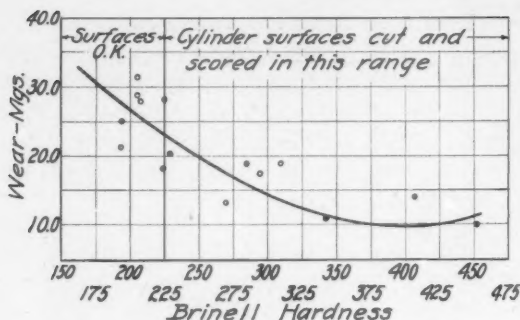


FIG. 9. ALLOY HEAT-TREATED CAST IRON. CHART SHOWING RELATION OF WEIGHT LOSS TO BRINELL HARDNESS.

45. As seen from these results, lower wear values are readily obtained by suitable heat treatment, but at the expense of the mating or contacting surface. It was apparent, both by the "noise" and "screching effect" as well as by the subsequent drum finish as to which specimens scored and which did not. One of the hardened rings, which showed distinct scoring under our tests, was installed in a steam cylinder, and substantiated our conclusions.

Part 2

AUTO AND AERO RINGS

46. As has been previously mentioned, the irons so far discussed have been those of relatively large section size as cast, and used in a field of service where lubricating conditions are not as consistent as is found in automotive and related higher speed engines. The lubrication existing in the present day motor car is indeed, relatively speaking, of a high order and efficiently controlled. This also largely applies to the aeronautical field. It is also realized that manufacturers of these engines are, however, constantly striving to improve their product as is evidenced by the intensive work constantly being carried on to lengthen the life and lessen wear of all moving parts both through better materials and through design, such as in the lubricating and cooling systems, etc., these effects largely accounting for the high overall efficiency now had in engines of this classification.

47. The fact remains, however, that the piston ring service here, while possibly not entirely satisfactory, has in the main, kept

pace with these improvements. For the large majority of motor car engines, a plain unalloyed close grain individually cast ring has given good results. In the bus and tractor field, and also in aeroplane and diesels, there appears a need for a ring with improved heat and wear resisting qualities, particularly so where steel or cast iron liners of higher hardness are applied.

Cast Iron Automotive Size Rings

48. Comparatively little work has been done on this angle of the ring problem, but since the purpose of this paper is to relate our various results with laboratory wear tests, rather than to offer cures for existing shortcomings, some data are given in Table 8.

Table 8*

WEAR OF VARIOUS AUTOMOTIVE SIZE RINGS AGAINST DRUMS OF 230
BRINELL HARDNESS

2 LB. LOAD ON RING SECTIONS $1 \times \frac{1}{8} \times \frac{1}{8}$ In.

Wear Wt.										
Spec. No.	Loss Mgs.	Rockwell Hardness	Si.	S	Analysis—Per Cent					
					P	Mn	T.C.	G.C.	C.C.	
1S	8.2	100.6	2.84	0.052	0.45	0.61	3.75	3.06	0.69	
2S	13.4	101	2.84	—	0.48	0.60	3.86	3.07	0.79	
3S	15.1	102.5	2.82	—	0.51	0.68	3.79	3.14	0.65	
4S	15.2	100	2.86	—	0.45	0.60	3.83	—	—	
5S	15.8	98	2.46	—	0.42	0.76	3.74	—	—	
6S	17.5	100	2.86	—	0.48	0.56	3.75	—	—	
7S	19.4	102.5	2.87	0.066	0.44	0.62	3.83	3.09	0.74	
8S	20.2	99	2.67	—	0.23	—	3.88	3.17	0.71	
9S	21.1	100	2.46	0.065	0.30	0.48	3.93	3.18	0.75	
10S	23.4	100	2.73	0.087	0.33	0.70	3.83	3.11	0.72	

49. Irons Nos. 1S-7S-9S-10S (Table 8) were further tested starting with a loading of one pound, and increasing up to 5 lb. These results are shown in the graph, Fig. 10, each point on the curves being the average of three or more separate determinations.

50. From Table 8, a rather wide range of wear results is had with analysis of apparently similar percentages. Rockwell Hardness values also are similar in many cases, so much so that these divergent wear values are hard to reconcile. However, we are dealing here with extremely small sections, rapidly cooled, thus resulting in structures of such high density, and grain refinement, that even under very high power microscopic observations, some parts are as yet unresolved. It is believed, however, that an ap-

* These wear values are comparable only within this small ring group.

preciable part of these differences may be accounted for in the graphite formations. These formations for Irons 18-78-98-108 are shown in the photomicrographs at 100 diameters of Fig. 11.

51. It is interesting to note that the No. 78 iron, which shows an unusually uniform graphite precipitation, does not give the best wear values, so that other factors must also largely contribute. In spite of the high silicon and carbon contents carried by these

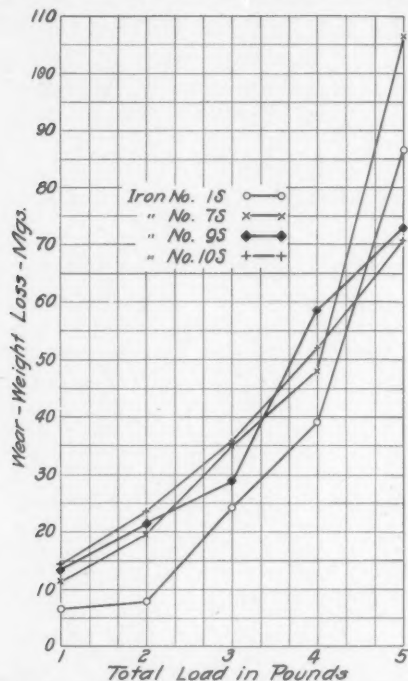


FIG. 10. CHART SHOWING RELATION OF WEAR IN AUTOMOTIVE PISTON RINGS WITH INCREASING LOAD.

small ring irons (usually associated in the minds of many with low physical properties), they all show, as tested on the actual ring sections, tensile strengths of over 40,000 lb. per sq. in.

Aeroplane Engines—Steel Cylinders

52. Some little work has been carried out in conjunction with two leading aircraft engine builders in an attempt to establish a suitable basis for further engine block tests using various cylinder

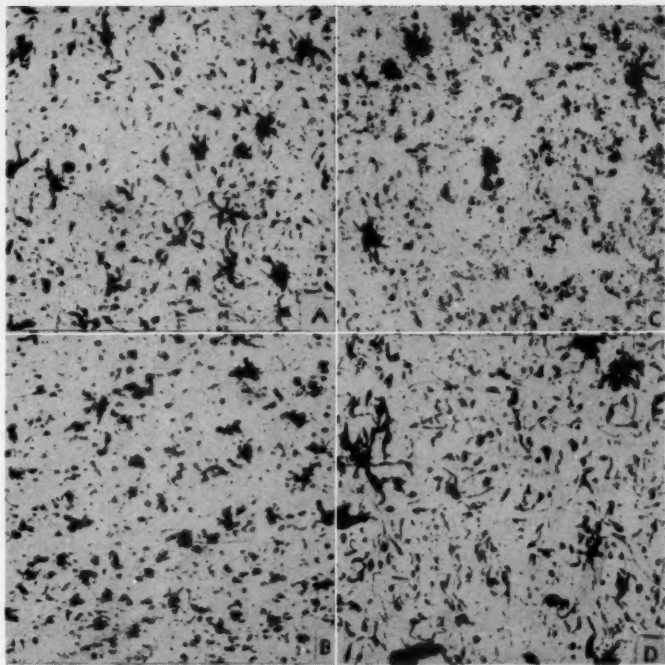


FIG. 11. VARIOUS SPECIMENS OF AUTOMOTIVE PISTON RING IRON, UNETCHED, 100X.
A—IRON 1S. B—IRON 7S. C—IRON 9S. D—IRON 10S.

and ring materials. Some of these findings were given in a paper by Robert Insley, United Aircraft Manufacturing Corp. at the 1936 Annual Meeting of the Society of Automotive Engineers. Steel specimens were machined from aircraft engine cylinders of various types and hardness, on some of which, fortunately, service results were available. The test procedure here was such that the wear of both "ring" and "cylinder" was determined, the "ring" in this case being the revolving drum, and the "cylinder" the specimen.

53. Three different ring irons were run against eight different steel cylinder materials and ring and cylinder wear determined. The results, shown in Tables 9, 10 and 11, while not in all cases actually duplicating service results, did so to a large enough degree to consider them of definite value as a guide to further dyna-

mometer or service tests, and this piloting data was obtained in a relatively short period of time and at little expense.

Table 9
PISTON RING IRON USED IN AIRCRAFT CYLINDER TESTS

	Iron A	Iron B	Iron C (H.T.)
Silicon, per cent.....	1.88	2.02	1.96
Sulphur, per cent.....	0.080	0.080	0.075
Phosphorus, per cent.....	0.39	0.42	0.37
Manganese, per cent.....	0.51	0.46	0.47
Total Carbon, per cent.....	3.57	3.63	3.54
Graphitic, per cent.....	2.82	2.93	2.91
Combined, per cent.....	0.75	0.70	0.63
Nickel, per cent.....	—	1.71	1.26
Chromium, per cent.....	—	0.34	0.22
Molybdenum, per cent.....	—	—	0.17
Brinell Hardness No.....	260	235	410

Table 10
DETAILS OF CYLINDER MATERIALS TESTED

Spec. No.	Steel S.A.E. No.	Hardness, Vickers No.
1.....	1050	184
2.....	1050	240
3.....	4140	315
4.....	4140	230
5.....	4140	410
6.....	2512 (0.035 in. case)	695
7.....	Nitraloy "G" (0.15 in. case)	975
8.....	Chilled Iron	870

54. From these tests, it is apparent that wide variations in rate of wear are indicated, depending on the particular type materials used in any combination. To point out all the trends indicated from these results would add undue length to this paper. However, certain of the more definite indications might well be mentioned.

55. First, regarding cylinder wear, it is seen that up to a hardness of 315 Vickers, cylinder wear is increased with the hardened piston rings, while from 400 Vickers and up, wear is in general less than with the softer ring compositions. That wear is determined by features other than hardness is strikingly illustrated by comparing the wear of cylinders Nos. 3 and 8. The latter, though more than twice as hard, gives a wear value four times

Table 11

WT. LOSS IN MGS.—COMPARABLE ONLY WITHIN THIS GROUP

Ring Iron	<i>Cylinder Wear</i>							
	1	2	3	4	5	6	7	8
A	6.3	6.3	4.2	9.1	3.8	7.1	2.8	22.4
B	9.8	6.8	3.7	6.9	3.6	6.5	3.5	18.1
C	14.8	16.2	4.6	8.4	2.3	4.5	2.7	18.6

Ring Iron	<i>Ring Wear</i>							
	A	B	C	A	B	C	A	B
A	54.3	61.4	61.6	50.8	61.4	54.8	65.2	62.5
B	49.4	50.6	58.5	46.1	61.6	58.8	...	35.2
C	33.1	38.8	37.9	—	39.0	35.2	33.2	26.2

higher than the No. 3 cylinder. In this case, the No. 8 material, after only a short time on test, wore rapidly due to the formation of transverse cracks which soon spalled off with resultant high weight loss. The No. 4 cylinder specimens were obtained from a cylinder which had worn out in the "green test," and the wear in service of this material in this form was generally unsatisfactory, and its use is now largely discontinued.

56. It is also the writer's understanding that cylinder materials Nos. 1 and 2 have been replaced by the No. 3 material, with marked improvement. Cylinder materials Nos. 5 and 7, while showing somewhat better wear than the No. 3, are, at the present time, limited in use due either to machining difficulties, or for economic reasons. It is of interest to note that the good wearing cylinder materials, give good relative wear values over a wide range of ring hardness, the poorer wearing specimens showing poor against rings of both low and high hardness limits.

57. As regards ring wear, it is seen that the cylinders of higher hardness generally give more ring wear against rings of conventional hardness, but have little effect on the hardened rings of 410 Brinell. The ring iron *B* (Table 9) containing nickel-chromium, shows a lower average wear than the iron *A*. The heat treated ring iron, containing nickel-chrome-moly, gives, against all the cylinders the lowest wear values of the three, though its use up to the present has been limited due to other factors bearing on its actual service application.

58. Reference might well be made to another case of interest. The No. 3 cylinder steel showed good wear characteristics over a wide range of combinations. Its etched structure is shown in Fig.

12A at 500X. Fig. 12B at 100X shows the appearance of the "worn surface" after one hour's operation.

59. Our comments from this report are as follows:

"Showing center of worn section after polishing. Dark areas are "pits" or valleys of normal metal, with the white scale of "worked" metal in the plane of focus. Numerous hair-line cracks are visible, appearing similar to a crackled varnish coating over the surface of normal metal. This is believed to be amorphous material formed due to the heat and frictional forces resulting under test. Previous observations indicate that the cylinder material, Fig. 12A, is particularly susceptible

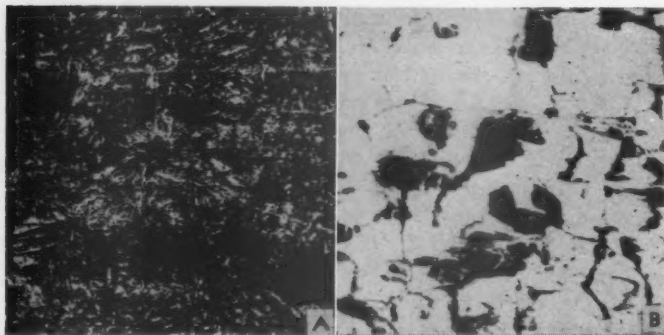


FIG. 12. A—STEEL CYLINDER MATERIAL, BRINELL 300, ETCHED, 500X. B—APPEARANCE OF WORN AREA AT END OF ONE HOUR RUN, 100X.

to this "filming" or surface flow. Films of this type, providing they are tenacious, very probably result in retarding wear."

60. This phenomenon occurs also on cast iron frictional surfaces, and has been referred to previously. It is believed that further study of this "interstraining" or "work effects" would yield fruitful data. Before leaving the steels, it might here be said that severely cold worked, fine grained compositions, in general again, seem not to have inherent wear resisting qualities found in coarser grained "distinctly crystalline" alloys.

INFLUENCE OF SERVICE CONDITIONS

61. To illustrate to some degree how service conditions may influence results, note Figs. 13 and 14. Fig. 13, at 25X, shows the

contacting surface of a small piston ring removed from an auto engine after several years' service. This specimen was washed with alcohol and photographed with no surface preparation. The etched appearance was visible when first removed from the engine. The network of phosphides is in slight relief and have taken an excellent "seat" with no sign of "scoring," etc.

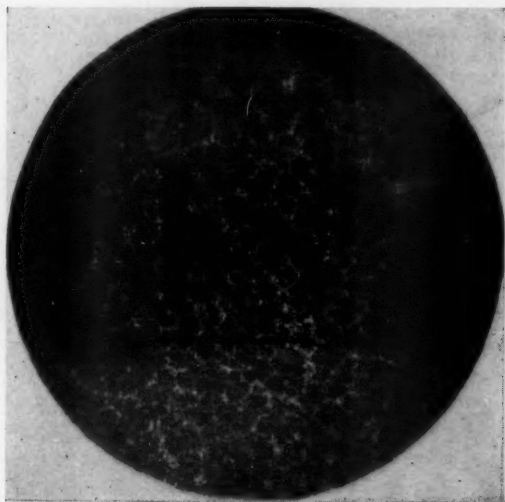


FIG. 13. OUTSIDE SURFACE OF AUTOMOBILE OIL RING AFTER SEVERAL YEARS SERVICE, 25x.

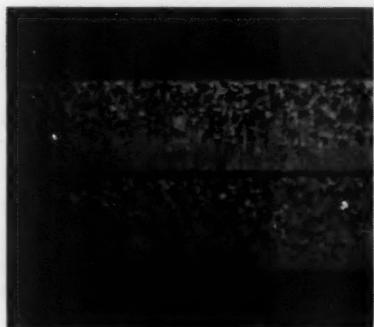


FIG. 14. EXTREMELY PITTED OUTSIDE SURFACE OF AIRCRAFT RING AFTER LESS THAN 50 HOURS, 7x.

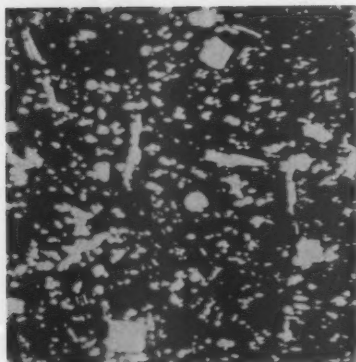


FIG. 15. ANTIMONIAL BABBITT METAL STRUCTURE.

61a. Fig. 14 shows at 7 diameters the contacting surface of two rings of somewhat similar section after less than 50 hrs. operation, "scored," "feathered," and seriously "pitted" and worn.

61b. Fig. 15 shows an antimonial babbitt structure of extreme heterogeneity as to hardness of constituents. For best wearing qualities in gray cast iron, approach to this type of structure might be made.

Part 3

BRONZE AND COMBINATION WEAR TESTS

62. In the development and study of bronze alloys for use in piston rings, the wear testing unit herein described was utilized also to advantage. Somewhat more difficulty was had in obtaining specimens which would give "check" runs than with cast iron specimens, this being largely due to "filming" effects on the drums. Finish and temperature variations also seemed to have more bearing on results obtained. However, in the course of these tests we learned to control these variables to a great enough degree to give, with a suitable number of runs, reasonably accurate results.

62a. Practically all of these tests were run against cast iron drums of 220 to 260 Brinell hardness. Some results from several bronze alloys are given in Table 12.

63. Fink, and others have reported very poor wearing qualities with die or chill cast bronzes, and our wear test results substantiate this conclusion. One die cast brass alloy of 60 copper-40 zinc composition showed 305 mgs. weight loss in one hour, under standard conditions, and another die cast bronze approxi-

Table 12
TEST RESULTS OBTAINED ON BRONZES

Specimen No.	XA	XB	XC	XD	XE	XF
Copper, per cent.....	80	78	76	82	80	88
Tin, per cent.....	15	17	19	17	19	10
Lead, per cent.....	5	5	5	1	1	2
Brinell (1 in. Section)....	100	134	159	125	148	70
Wear—Wt. Loss in Mgs...	36.3	37.6	53.4	18.7	19.8	18.1

mately 81 copper, 4 tin, remainder zinc showed 763 mgs. weight loss. Though it must be stated in all fairness these two alloys were not designed for bearing service, it was nevertheless very striking to note the manner in which they powdered away, covering the entire test apparatus with bronze dust while a specimen of the XD type, running on an opposite drum would lose only 20 mgs. indicating nearly 40 times better wear resistance with the latter.

64. Another similar case was encountered while testing two centrifugally cast bronze sleeves, from which specimens were prepared, with the results given in Table 13.

65. The *JTW* fracture was very coarse, irregular and would have limited application either in a ring or where reasonable physical properties were required. Conversely, the *NTW* fracture was extremely dense, fine grained, and of high physical characteristics. Yet in spite of these, this specimen showed very poor wear. The same alloy, cast in sand, with similar section, resulted in great improvement as shown.

66. With the non-ferrous alloys, as with the cast irons, it appears, at least from test results, that if grain refinement is carried too far, even though good density and hardness are ob-

Table 13
RESULTS OBTAINED ON CENTRIFUGALLY CAST BRONZE

	Spec. No.	WearWt.Loss Mgs.	Brinell Hardness	Cu %	Sn %	Pb %	Zn %
Centri. Cast	JTW	14.9	96	85	10	4	1
" "	NTW	478.0	160	80	15	5	—
(Sand Cast)	ATW	37.0	140	80	15	5	—

tained, poor wearing qualities are obtained. It is equally true that a good wearing alloy may, due to its entire lack of other necessary properties, be entirely eliminated from consideration.

67. Such findings seem to show that an "all encompassing" single alloy or metal may be as difficult of attainment as the alchemists' search for a base metal for transmutation into gold.

68. Shortly after these tests were started, the question was raised as to what effect would be obtained with a combined specimen of iron and bronze. It had been observed that, on locomotive pistons, wherein the badly worn ring grooves were built up by brazing with manganese bronze welding wire, improved ring and cylinder wear was obtained. It was reasoned that this was likely due to the effect of the bronze on the cylinder surface, tending to reduce chances for "scuffing" or "seizure." Quite some success had been also obtained with piston rings of the "Gold Seal" type, these having a strip of bronze pressed into a groove machined in the outside diameter bearing surface. Beside less ring and cylinder wear in these installations, much quicker seating in, and apparently more efficient sealing was obtained, along with lessened "scuffing" tendencies.

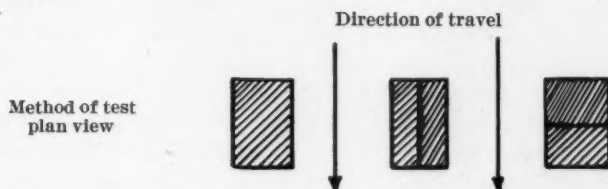
69. Test specimens were prepared consisting of various proportions of iron and bronze. These were held together as a unit specimen, and tested in this manner. One can, of course, readily realize the infinite number of combinations possible, what with varying proportions and of the various iron and bronze structures available. No pretense is made that we have found the best possible "unit", but by using several bronze alloys with which we were familiar, and which were readily cast under our methods of manufacture, (many of which had been used as piston rings in various applications), we obtained some most interesting results.

70. Specimens of "half and half" (50 per cent iron combined with 50 per cent bronze) seemed most promising. We found that if a specimen made up in this manner, was operated so that the two different metals operated on their own "track", no improvement was had, but if operated on a common "track" rather startling reductions in weight loss or "wear" values were had over either metal operating alone. Table 14 reproduces the data for this test.

71. It is evident from the above figures that, unless the two dissimilar metals are arranged so that they operate on a mutual track, no reduction in weight loss values are obtained.

Table 14
RESULTS OF "COMBINATION" WEAR TESTS

Determination No.	"Wear" Weight Loss in Milligrams		
	Poor Wearing Iron	50-50 Comb. Lengthwise	50-50 Comb. Across
		Separate Tracks	Same Tracks
1	48.4	64.7	18.4
2	31.3	77.5	15.1
3	48.9	61.0	20.5
4	35.7	41.8	24.1
Average	41.1	61.2	19.5



72. To further illustrate this effect, Table 15 is shown with some results obtained during this research.

73. Irons A, B and C were poor wearing structures, but in combination operation resulted in good wear-test ratings. Irons D, E and F were nickel-chromium compositions of good wear resisting qualities. These, however, were substantially improved by "combination".

74. This feature of two widely different materials operating as a unit may not be new but it is believed that its advantages, at least from a bearing angle, have been largely overlooked in present

Table 15
EFFECT OF COMBINATION METALS

Test	Wear-Iron	Wear Bronze	Wear Value
	Alone Mgs.	Alone Mgs.	of Comb. Mgs.
A	42.8	122.4	24.1
A' Recheck	36.7	114.0	26.5
B	42.8	88.0	21.6
B' Recheck	36.7	72.7	22.7
C	32.0	80.3	22.9
D	23.2	80.3	16.9
E	17.0	53.4	15.7
F	17.0	19.8	10.8

day engineering applications. A recent reference is given this subject in the article by Saito and Yamamoto, appearing in the June 1935 issue of *Metal Progress*. The writer has also heard of using cast iron bearings which were drilled with holes, these being filled or plugged with hard wood which apparently reduced friction loads, and retained some lubricant. Probably a great many similar cases will be recalled by the reader.

75. After getting these laboratory values, it remained to be seen if these improvements in wear were obtained in actual service. At this writing, service results with several hundred rings of this type in compressor steam, and diesel service, seem to tie in with wear test results. Some failures have resulted but by a large margin, this application seems outstandingly successful. In several cases, where these rings were installed in locomotives in one cylinder, the conventional rings being in the other cylinder, as many as 10 sets of "good wearing" iron rings have worn out, during which period a single set of iron-bronze combination rings were performing beautifully. Increases in life of 4 to 6 times are quite usual.

76. If we knew better how to "gauge" or "rate" a "film" condition, we would be better able to explain why the above results are obtained. However, reduction of friction coefficients is a factor. Furthermore, the bronze portion seems to "condition" or "grease" the two iron contacting surfaces with consequent reduction in tendencies to "seize" or "gall". The ring design in this application is such that rapid wear of the relatively soft bronzes appears to be retarded by the presence of the harder cast iron portion, which seems not to wear due to the "film effects" of the bronze. Reduction in tendencies to "rust" or readily oxidize the bearing surfaces, particularly in steam applications, is, no doubt, a contributing factor.

77. This same thought has been carried out by using "babbitt metal" strip inserts in the iron portions of rings with equally improved service in fields of lighter duty and lower temperatures.

78. It is believed that great strides may be made in application of metals for bearing service by such combination methods. Even two highly different cast iron structures, combined to operate as a unit may be of practical value.

COMMENTS

79. In the initial preparation of this paper, the author in-

tended only to describe the testing machine, and cite a few cases where, particularly in the larger section rings, it had proved useful in developing and improving their wear resisting qualities. The original thought was to deal only with gray cast irons. It was later suggested, however, that the data given in the latter part of the paper regarding airplane cylinders, bronze-, combination, etc., be included. This has been done, though much detail has had to be omitted. The writer now finds it desirable before concluding, to discuss in a necessarily general manner some "impressions" gained during the course of this research. These are in no manner to be considered as final, but represent beliefs and indications at the time this data was prepared. Due to the scope covered in the preceding pages, certain exceptions may be overlooked, but it is hoped that the general manner in which this will be attempted, will at least, largely apply to the foregoing tests.

Effect of Drum Finish

80. The little work done along these lines indicates that in actual service, finish is an important factor. In some few tests, where we compared weight loss values when operated against both turned as well as against ground drums, considerably more wear resulted with the ground finish. It is not known at this time whether this is a result of imbedded abrasives, or due to the more intimate contact of specimen and cylinder. We believe, however, it is due mainly to the latter.

81. The writer is of the opinion that much might be accomplished, particularly in finishing cylinders, by giving more consideration to what has been called "affinitive" surfaces*. Cylinders finished co-directional with the ring travel, should substantially reduce initial wear over those finished normal to the piston movement.

82. To carry this further back, it would be interesting in the case of forged steel liners and cylinders, to see whether any changes in forging practice might be made to incorporate this co-directional effect in the body of the steel.

83. As to the effect of the contacting metal on the "wear" of various irons, the following might be said: Most of our tests were run against an iron of "medium grain" with a hardness of 230 Brinell. This is an attempt to represent an "average" condition as regards contacting surfaces encountered in the field. A varia-

* Kline, J. E., "Desired Characters of Surface Finishes." TRANS. A.S.M.E., December, 1935.

tion of plus or minus 30 points of Brinell, *i. e.*, from 200 to 260, seemed to show little or no influence on our results. Neither did the addition of nickel-chromium to the drums, (1.00 Ni—0.30 Cr.) alter the picture. Against alloy heat-treated drums of 400 Brinell, several specimens showed from $1\frac{1}{4}$ to 2 times as much wear under otherwise similar conditions.

84. Operation of steels against cast irons of several types and hardness, indicated somewhat greater wear of the cast iron, as steel hardness increased. More work needs to be done along these lines; however, to a large degree, it has been indicated that a good wearing iron or structure gives good wear results over a rather wide range of hardness, finish, etc., *i. e.*, though the wear value may be greater or less than under a standard set of conditions, a "good" wearing iron shows relative better wear resistance, than does one which showed "poor" under standard conditions. While the "spread" between the "good" and "poor" iron may vary, we have not encountered anything which approaches a complete reversal.

DISCUSSION OF CAST IRON STRUCTURAL FEATURES

Graphite

85. Very "fine" or "sooty" graphite, particularly of the type resulting from "undercooling," is usually indicative of poor wearing qualities. (See Figs. 8C and 8D.) This appears to be true over a wide range of hardness values. Gray irons, when annealed, to a ferrite-graphite structure, wear very poorly. Considerable work has been done in England and Germany in determining the cause and manner of formation of a "supercooled" type of graphite. Investigations by Nipper and Piwowarsky indicate generally poor wearing qualities with this type of structure. This is confirmed by our own experiences wherein any approach to an extremely finely divided graphite precipitation, under dry operation, results in impaired wear resisting properties.

Grain Size

86. Coarse, or moderate-grained irons seem more resistant to wear than do those of the fine-grained structure. Hence, grain-size exerts a major influence in determining wear resistance. A recent discussion* relative to grain-size in cast iron attributes the size of the resultant network or mesh formation (made up mainly

* Murphy, D. W. and Wood, W. P., "Austenitic Grain Size in Cast Iron," TRANS. A.S.M., March, 1936.

of phosphides and carbides), as dependent on the initial austenitic size. While this may not at this time be entirely accepted, it is, nevertheless an interesting sidelight. At any event, the grain-size of iron, indicated by this network, as well as the graphite sizings before mentioned, seem largely to influence wear characteristics.

87. Irons having network formations, which are "heavy bodied" seem to have (other conditions being apparently equal) better bearing qualities than those wherein this mesh formation is "thin-lined." One might almost suspect here that more intimate and stronger joining, or more and better "cementing envelopes" exist with the heavier networks. Possibly what might be called "good intercrystalline cohesion" is what is desired.

88. We do not know exactly why moderate or large micro-constituents enhance wearing qualities, but a great many observations seem to point to this being the case. We do suspect, however, that in some irons, the "effective" grain size is so small that the abrasives normally encountered in both dry and lubricated wear actually tear out the small crystals or at least seriously weaken and loosen them from the body or matrix. These same size abrasives cutting into a larger grain or "crystal" (it must be remembered that they are "large" in three dimensions) are then possibly only "surface scratched" or "nicked." Having more area of contact with the surrounding matrix, due to their greater volume, they might be expected to be more securely held, so that further rubbing effects close over the initial scratches without loosening of the entire grain. Thus, depending on the tenacity with which they are "keyed" into the matrix, they may be better able to resist this continuous "scratching and filling-up" action, than would a smaller grain. If the iron or metal is of the type which tends to "glaze" or "film," this cutting action gradually decreases in intensity finally becoming fairly uniform and we have what we consider "normal" wear. If such is the case, even to a degree, we can readily appreciate why finely divided, high carbon irons, powder away so rapidly under dry wearing operations.

89. The above is not in accord with the present-day theory regarding *strength* of metals, based largely on the fact that through grain refinement, promoting better uniformity, more secure "keying," and fewer planes of weakness, we obtain maximum physical properties.

90. However, the mechanism of wear, under conditions of

friction and abrasion, quite likely results in a large number of extremely localized stresses on each and every crystal making contact. In a tensile test coupon for instance, the load is carried more or less equally by the whole section or body of the test piece, fracture finally taking place due to initial failure of the weakest (or most highly stressed) crystal in the section. "Wear stresses" however, may be said to act individually on each crystal, so that possibly the degree of wear is determined more by the "mass" and "makeup" of each "unit grain" rather than by their "composite effect."

Section

91. From the section on grain-size, it may be stated that "mass" and "section size," or cooling rate influence wear to a greater degree than chemical composition. In general, the same iron, poured into varying section sizes, will exhibit its poorest wearing qualities (under dry operation) in the lighter sections, and improve in wear resistance as section size or "mass" increases. This again reverts to "cooling rate" effects and resultant grain size. This, along with the carbon content of the iron, may, in the main, determine wear resistance.

Phosphorus

92. Phosphorus, particularly if present in a heavy bodied network, appears to aid in resisting wear. Our impression is that some definite improvements in wear resistance may be had in irons of rather low phosphorus content by increasing the percentage of this element. We have not encountered any cases of this constituent spalling off and acting as abrasive in iron of normal structure, though we believe this may likely happen if the steadite is present in a too finely divided form.

Sulphur

93. High sulphur seems advantageous. It appears that the presence of sulphides, conferring as they do, additional heterogeneity to the structure aids resistance to wear.

Total Carbon

94. For a given type of structure, best wear is had with total carbon contents of 3.40 per cent and under.

Matrix

95. Coarse pearlite, definitely laminated, usually indicates improved wear resistance over the fine or sorbitic type.

Alloys

96. Alloy additions improve wear, often to a marked degree, by raising the effective hardness. However, if grain refinement is carried too far, or if the iron is made too "structurally homogeneous," a decrease in wear resistance may be had because of such additions.

Pouring Temperature

97. Very high pouring temperatures (about which we have heard a great deal in the past few years), if resulting in very fine grain, may result in impaired wearing qualities.

Melting

98. Melting medium, be it cupola, air furnace, or electric, influences wear only insofar as their ability to reproduce a desired structure is concerned. Both "good" and "poor"-wearing irons may be readily made in any of the three.

98a. The above statements are, as has been previously mentioned "impressions" only, which at this time seem to hold true, but which further research and experience may prove erroneous. They are an attempt to summarize, in a general manner, conclusions indicated from our tests which have been in part treated in this paper.

CONCLUSION

99. For the sake of brevity and to avoid repetition, no detailed summary will be given. This paper has been prepared from a practical rather than theoretical angle, both for the reason that it is hoped it might be of greater value in this form, as well as for the fact that, in some cases, the theories are not too convincing, and at best, would be quite lengthy in themselves. Often, in compiling these data the writer has been at a loss as to how to describe or depict a resultant surface condition; hence, the frequent use of the words "glaze" or "film," when possibly these may not convey the true impression. It has been found equally difficult to measure or record photographically these various surface effects. It is hoped, therefore, that some indulgence will be given in this respect.

100. What we have attempted to do is to describe a laboratory method for compiling wear data by means of a simple and practical apparatus or "comparator." We believe that by use of such a machine, though in itself, far from duplicating actual service conditions, we have been better able to define lines along which wear-resisting structures should be developed in metals, particularly gray cast iron, realizing at the same time that in many cases these may not always be incorporated, due to other important factors. Attention is again directed, however, to the fact that in these tests we are dealing only with "bearing qualities" in dry sliding, or "rubbing" friction.

101. Some examples have been given, typical of our experience, but possibly not typical of others. No claim for originality is made, but rather only the hope that that which has gone before may incite further study of this fascinating "quality" in an endeavor to find the answers to the many phases which yet remain hidden.

ACKNOWLEDGMENTS

102. Much of the data herein presented, particularly that where service experience is recorded, were available only through the cooperation of customers in the solution of problems of mutual interest, and to whom thanks and appreciation is expressed. Thanks also must be given my associate, Arthur Reese, whose care in performing many of the tests and analyses has, to a large degree, contributed to the success had in these investigations.

DISCUSSION

Presiding, S. C. MASSARI, research metallurgist, Association of Manufacturers of Chilled Car Wheels, Chicago, Ill.

D. E. ACKERMAN¹ (*Written Discussion*): This is a very interesting paper and indicates the expenditure of a great deal of time-consuming work.

The test machine is similar to that described by Connelly at Lehigh about two years ago, but whereas Connelly used his machine to measure the maximum working pressure and the rate of wear after this pressure has been obtained, Mr. Lane, I gather, uses his equipment to measure the weight loss during the earlier part of the wearing in period. It is not clear how long a typical piston ring iron must be kept on the machine in order that it may attain a constant bearing pressure and I think the

¹ Research Laboratory, International Nickel Co., Bayonne, N. Y.

inclusion of such data would add to the interest in Mr. Lane's paper. The use of a test period as short as one hour for gaging the relative wearing properties of irons which will be used for long periods of time may raise some discussion, for the test conditions during this period are such as would exaggerate any differences which may exist between the irons being compared. While Mr. Lane includes many data showing that his test will differentiate between irons of similar composition but of radically different microstructure, I think additional examples of the correlation of wear test data with surface life would be highly acceptable for I found very interesting, correlations of this type which are now included.

As Mr. Lane implies, the plain irons with coarse pearlite and coarse deeply embedded graphite flakes, particularly if they contain phosphides, have been recognized to have better wearing properties than those with small patches of fine pearlite and very finely divided graphite which can be dislodged. The merit of nickel-chromium irons resides in the development of the microstructure which also contains graphite in a difficulty dislodgeable dispersion, together with chromium carbides which re-enforce the bearing action of the pearlite. I think Mr. Lane's test results showing the coarser-structured, plain irons to be superior to the finer structured plain irons are completely in accord with experience.

It would be very interesting if Mr. Lane could include some data showing that his test will predict the relative surface life of irons of given microstructure, but of different compositions and possibly different hardnesses.

The problem of film is so important in wear test that, any amplification that Mr. Lane could make of his few remarks about glazes would be welcome. Some further remarks about the effects of varying test temperature resulting from frictional heat might be well, also. Mr. Lane remarks that all specimens attained about the same final temperature; presumably this resulted from the fact that the irons were similar in type and test temperature might easily become an important variable if a series of irons of different hardness were to be tested. In this connection, I wonder whether the spalling of the hard iron, mentioned in paragraph 40, may have resulted from a high surface temperature.

W. E. JOMINY² (*Written Discussion*): As is well known, one of the most important properties of cast iron is resistance to wear. It is perhaps equally well known that most attempts to measure this property of iron, aside from service tests, have yielded only indifferent results. The reason for this lack of success is at least in part due to the complexity of the problem. In all types of wear testing, an attempt must be made to speed up the process and in speeding up the process some factors affecting wear are given an emphasis which is out of proportion to their importance in service. This, however, is no reason why we should give up the attempt to perfect a real wear test and I believe the author is to be complimented for his work in this direction. Considering the importance of wear re-

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sistance of cast iron and the great need for accurate data, it would seem that a great deal of research work should be in process on this subject.

In a recent symposium on wear at Philadelphia, a statement was made that a wear test must be tailored to fit the intended service application and that no such thing as a standard wear test can be attained. It should, however, be possible to eventually obtain a standard wear test for cast iron intended for automotive piston rings and cylinders. So many people are interested in this particular type of wear that standardization would be very worth while. In the meantime we must compare results from several types of machines.

The results obtained with our wear test machine have been in agreement with many of the results reported by the author. We have found that with some compositions of cast iron the section size into which the cast iron is poured affects wear, the poorest results being obtained with the lightest section. This is in agreement with the author's statement in paragraph 91. In our recent experience, however, certain compositions, particularly those with a fair percentage of chromium, show little if any difference between sections as light as $\frac{1}{4}$ sq. in. cross sectional area and as heavy as 12 sq. in. Our experience with high phosphorus cast irons is also in accordance with the author's statement in paragraph 92. We have not found high sulphur to be advantageous, as stated by the author in paragraph 93, though our experience is very limited with the effect of this element.

We cannot, of course, expect too close agreement between the results obtained with our machine and the author's in that the machines are constructed and operated quite differently. Some of the more important points of difference are that we use a lubricant composed of a mixture of kerosene and lubricating oil, that our machine is operated with constant friction and that we use very much higher loads than the author. With these rather wide differences, it is interesting to note that our results agree at all.

It has been observed that certain of the more outstanding wear characteristics are checked by nearly all wear test machines. However, there are rather large differences in the rating of cast irons and other metals by various machines and a great deal more work needs to be done to properly evaluate the results obtained.

I believe the author has presented data worthy of our very careful consideration.

P. S. LANE (*Reply to Written Discussion*): I wish first to thank Mr. Ackerman for his interest in submitting this discussion.

In reply to his question as to how long a typical piston ring iron must be kept on the machine in order that it may attain a constant bearing pressure, it has been pointed out in paragraph 15 of the paper that, at the end of a test period, a poor-wearing iron ends up under somewhat less unit pressure than a good wearing iron. Were the irons to reach a constant bearing pressure, it would be necessary to run them until the full width of the specimen, which is $\frac{1}{2}$ -in., is in contact with

the drum. One series of tests were made on a good and a poor-wearing iron with the following results:

Time required for poor-wearing iron to come into complete contact with drum.....	4 hours
Time required for good-wearing iron to come into complete contact with drum.....	19 hours
Weight loss of poor-wearing iron after 19 hours' running..	602 mgs.
Weight loss of good-wearing iron after 19 hours' running..	181 mgs.
Maximum penetration of poor-wearing iron.....	.054"
Maximum penetration of good-wearing iron.....	.016"

From the above values, it is seen that it requires nearly five times as long for the good-wearing iron to come to a complete contact, and results such as these certainly tend to make one believe that the good-wearing iron seems to have the ability to form a wear resistant film or glaze which greatly increases resistance to wear. The exact mechanism of this is not as yet known but, in the above tests, it was observed that both the specimen and contacting surface of the good-wearing iron attained a mirror-like finish.

We agree that the short duration of the tests would be likely open to question but further check runs up to as long as three hours' duration have shown quite the same proportions regarding wear values. Aside from the saving in time, the shorter tests allow more individual runs on different surfaces of the same iron which, in our opinion, gives a fairer average than does one prolonged test on only one surface. For instance, in taking hardness readings of a piece of metal, one always takes readings at several different places and computes the average and, in taking these several readings, finds that the hardness lies within a certain range rather than at any one fixed reading. Thus, while our tests may show somewhat larger variations on the same piece of iron, when run against a different surface of this piece, we feel that this really gives us a truer indication of the wear resistance.

I am pleased to note that Mr. Ackerman agrees that some of the coarser structure plain irons show superior to the finer structure irons and that this is in accordance with experience. Regarding their request for further information on irons of given micro-structure but of different composition and hardness, we have no new data at this time to add. Similarly, regarding the formation of film or glaze, I regret that here again we are not in a position to say much more than has already been submitted, though some further work is in progress regarding this.

It has not been our practice to measure the temperature of all specimens, so it is entirely possible that, in the case of the chilled iron mentioned on page 172, the high wear may have been a function of the high surface temperature, although micro-examination showed that the surface of this particular specimen was covered with transverse cracks indicating that, in this case at least, the high wear was largely the result of a spalling action.

Mr. Jominy's discussion was indeed very kind. He is doing a lot of fine work on wear testing and, quite naturally, we are pleased that we

checked as well as we did. I think that his machine, since it is operated under conditions of lubrication, probably approaches automotive service conditions more than ours, and if we are able to change both of them around and end up with something that is in between the two, it may be we will have the right machine. We know that this property called "wear" is certainly interesting, and we hope that we are going to move along a little faster on it.

CHAIRMAN MASSARI: I am sure we are all immensely interested in the problem of wear. I am, particularly so. Our problem is one radically different from this type of wear. We are interested in chilled iron, operating under much higher intensity of pressure and our wear tests are conducted under entirely different conditions. We are interested in dry abrasion under very high pressures.

R. E. SCHNEDEWIND³: I found Mr. Lane's paper most interesting. Perhaps I should not discuss our work in connection with it, because we were not measuring wear. About a year ago we carried on an investigation on the wear resistance or, rather, the scoring resistance of brake drum irons against brake linings, and the test we used might be rather crude. We ran iron drums against a standard brake lining at a constant pressure, and it is very interesting to see that our conclusions were substantially in agreement with Mr. Lane's. We found that if you had a given matrix, for example pearlite, the softer the pearlite, the better the wear resistance. We found also that more graphite of the same shape was better than a lower amount of graphite, and that flake graphite resisted wear much better than the eutectic graphite.

As to the effect of alloys, we found that the addition of such deoxidizing alloys as zirconium, which gave us good graphite flakes, also increased the resistance to wear. Copper is supposed to be a graphitizer but that reduced the wear resistance. Aluminum in large quantities (6 per cent) reduced the resistance to wear very much.

I think Mr. Lane's most valuable contribution is in throwing the subject open. It may be that the structure of the metal has greater effect than the composition or any given property, such as hardness. In any of these wear tests proposed, it would seem to me that if you can determine which structure and which condition will give you the best wear resistance then in the actual casting, you will have to produce that structure at the surface which is left after the machining is done.

E. EDWARD FLANDERS⁴: I have had occasion quite recently to work on the problem of wear and, while we have developed a test that correlated with the particular work we were doing, we found that it is just about as expensive as to do the actual testing.

In the September issue of *Metal Progress*, there is a discussion by D. S. Clarke and R. B. Freeman, California Institute of Technology, in which they base a wear test on the amount of power required to make a channel with a diamond point and measuring the volume of metal removed. We did not duplicate their equipment, but had the idea that if

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⁴ Supervising Research Engineer, American Rolling Mill Co., Middletown, O.

we could measure the power absorbed in grinding off a certain volume of material, we would have a wear test.

The bar of stock to be tested was placed on a magnetic chuck and ground to a high degree of smoothness and a strip selected for test. The wheel was run until there was practically no power absorbed, as measured by a watt meter and with suitable gauges the depth of cut was set to 0.002, 0.003 or 0.005 in., as was desired. Usually in the first pass, only about half the depth was removed and subsequent cuts were taken to complete the grinding until no power was used. By summing up the power that was actually absorbed in the removal of this volume of material, the work per unit volume was calculated. The results checked fairly closely, probably of the same order of agreement as was obtained by Mr. Lane and shown by the data on the screen. The results also correlated fairly well with the results we were getting in service with this particular type of material.

I just offer this as another wear test, which we are using on occasions to guide us a little in our work.

The study of wear testing is an extremely difficult one in which to get some system evolved where workers can actually find something to guide them in research. The results seem to be so erratic with the different types of materials. Hard materials, as was pointed out in Philadelphia at the symposium on wear, and in Mr. Lane's paper, sometimes wear more readily than soft materials, while on other occasions hard materials are so far superior to soft materials that there is no comparison whatsoever. The problem, then, is a matter of recognition of service conditions and complete appreciation of certain fundamental requirements which are dominant in each particular service. Any attempt to study and organize these principles seems a very worthy effort.

Portland Cement as a Binder for Foundry Molding Sand

By CARL A. MENZEL,* CHICAGO, ILL.

Synopsis

This paper provides information of general interest to foundrymen regarding the use of a portland cement as a binder in foundry molding sand. It presents results obtained in laboratory studies of the relative influence of various factors affecting the strength and permeability of cement-foundry sand mixtures. Among the factors studied were type of cement and cement content, moisture content, type of sand, extent of ramming, temperature and age of mix, etc. The studies have established which factors are important and which are of less consequence in the practical use of portland cement in the foundry.

The results obtained indicate the general feasibility of using portland cement as a binder in molding sand and provide a basis for suggestions and recommendations for such use.

INTRODUCTION.

1. The use of portland cement as a binder in foundry molding and core sand is not new. Cement has been used to a limited extent in this field for some 40 years and such use is mentioned in a book by Richard Moldenke on "The Principles of Iron Founding," published in 1917.

2. Although portland cement is one of the most highly developed and widely used mediums for binding particles of sand and stone together in concrete it has not been extensively used in foundry practice. Recently, however, there has developed a marked interest in the possibilities of cement for foundry use, which may be due to the combined effect of several factors. One of these is the intensive effort of foundry technicians to improve

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the quality and reduce the cost of castings. Another is the development and general availability of inexpensive high-early strength cements. A third factor which has stimulated interest are the reports of the excellent results obtained with cement binder in a process used in a few European and American foundries.

3. In response to this revival of interest and to requests for more definite information on this subject, the Research Laboratory of the Portland Cement Association undertook the studies reported herein with the cooperation of the American Steel Foundries. The writer gratefully acknowledges the cooperation of C. E. Sims, formerly Assistant Research Director of the American Steel Foundries in this work.

GENERAL CONSIDERATIONS AND SCOPE OF TESTS

4. There are several points which bear on the general success or failure of almost any binder in foundry sand molds. Briefly, it is desirable that after ramming, the mold have high "green" strength so that it can be handled without damage until the time the steel is poured a few days later. The surface of the mold should be hard and the mold should be strong, but not too strong as it is desirable that it yield somewhat under pressure of the steel as it solidifies. The mold should contain as little moisture as possible, particularly at the surface in order to avoid the sudden formation of steam. It must also be permeable for the escape of gases but the surface must at the same time be clean, smooth, and hard so as to provide a smooth surface on the casting. It is very important that the mold surface be free from materials which will lower the fusion point between the steel and the silica sand. Lime is particularly objectionable on the surface of the mold for this reason.

5. On the basis of these general requirements, it appeared desirable to divide these studies of cement binder into two parts. The first part includes a study of those factors which normally could be expected to influence the strength and permeability of a partially hardened cement-sand-water mixture at the age of about 3 days. The second part involves the development of a surface wash or other preparation with which the surface of the mold can be treated to prevent or reduce the "burning-in" or fusion of the steel with the silica sand at 2900°F.

6. This paper reports the results available thus far from the first series of laboratory studies. These have provided infor-

mation of general interest regarding the influence of such factors as type of cement and cement content, moisture content, type of sand, ramming, etc. and have established which factors are important and which are of less consequence. It is hoped that when this information is applied under actual foundry conditions, it will define and simplify the second part of the study which deals with the development of preparations or methods to give mold surfaces having desirable characteristics. This latter problem will require the cooperation of experienced foundry technicians.

7. It was apparent from the beginning that to maintain proper control and to secure uniform results with cement binder the face of the mold would have to be made from a carefully proportioned mixture of cement, suitably graded fresh, clean sand, and water. It seemed also that such a high-grade facing layer approximately one inch thick could be backed up with any suitable combination of lower grade materials. The studies were carried out assuming such a combination would be necessary in practice. For instance under one plan of operation all of the material available from a mold made of both high-grade cement-bound facing and a lower grade of cement-bound backing may be crushed and returned to individual sand grains to make the mixture to be used for back-up in the next molding. This mixture will contain some hydrated or spent cement. When it becomes loaded with too large a quantity of spent cement with repeated additions of new cement, the excess fines can be easily blown out. Under another plan the entire cement-bound mold may be crushed to form particles of varying size up to $\frac{3}{8}$ -in. or more to which new cement is added to form backing material simulating very lean concrete. Under a third plan the back-up may consist of light-weight aggregates such as slag, cinders, or burned shale (Haydite) held together by cement.

8. Whatever methods or materials are employed for backing up the facing, it should be emphasized here that one essential for success is a good facing layer of well-graded fresh, clean sand combined with the proper amount of cement and water. The re-use of the facing sand after the first mixing with cement results in a mixture having markedly lower strength and increased permeability even though as much new cement has been added as was used originally. It is doubtful whether the spent cement adhering to the sand grains can be removed sufficiently to return the sand to its original condition. The adhering cement separates the sand

grains and not only reduces the strength and increases the permeability of the facing but alters the surface characteristics and increases the undesirable lime constituents at the surface of the mold. This creates a condition favorable for "burning-in" and fusion with the steel. It, therefore, appears that uniformity in results can be obtained far more simply and more certainly, as well as more cheaply by using the high-grade facing exclusively for each mold. As already suggested, it was this concept which led to the procedure followed in these studies, and adherence to it should enhance the possibility for successful application of the results to foundry practice.

TESTS AND TEST PROCEDURE

9. The general technique used in the making and testing of

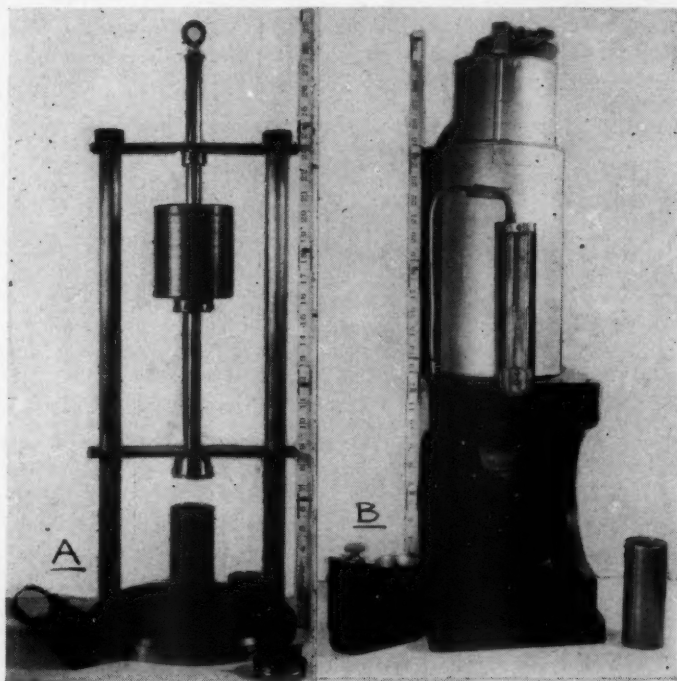


FIG. 1—APPARATUS USED IN RAMMING AND TESTING 2 x 2-IN. CYLINDERS FOR PERMEABILITY TESTS OF CEMENT-BONDED MOLDING SAND.

A. SAND RAMMER (STANDARD TYPE).—B. PERMEABILITY METER (STANDARD AIR-FLOW TYPE).

the cement-bonded laboratory specimens closely followed the standards of the AMERICAN FOUNDRYMEN'S ASSOCIATION in the new and revised edition, March, 1931, for "Testing and Grading Foundry Sands." Particular reference is made to the procedure described in Section V for Permeability Tests and Section VI for Strength Tests (compression only). The principal pieces of apparatus used are illustrated in Figs. 1, 2 and 3.

10. *Test Specimens.* These were 2 by 2-in. cylinders throughout. In molding, the mixture was rammed in the standard manner, unless specifically noted otherwise, by three rams or tamps of a 14-lb. rammer-head falling each time through a distance of 2 inches.

11. The compressive strength and permeability of these cylinders were determined "green" immediately after ramming, and "set" 3 days after ramming. In all except one group of tests, the cylinders were stored to retain the moisture present when rammed. Strength and permeability values both "green" and "set" are the average of 5 specimens.

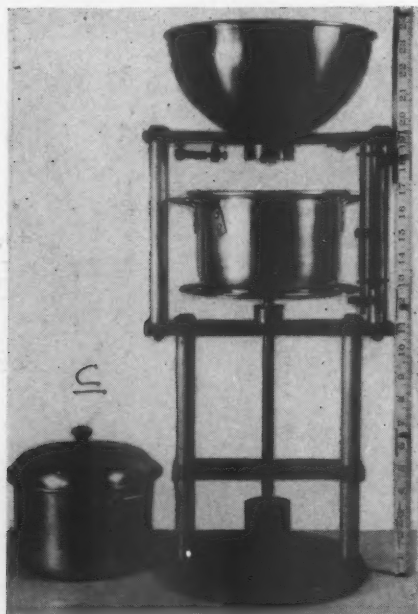


FIG. 2.—MACHINE FOR TESTING GREEN STRENGTH (MENZEL, DEAD WEIGHT DESIGN, CAPACITY 30 LB.).

12. *Sand.* Two typical silica foundry sands from Illinois and Missouri were used. They differed in grading and particle size distribution as indicated by Fig. 4.

13. *Cement.* Two types were used—normal (N) and high early (H.E.S.) strength portland cements. The normal cement was a mixture of equal parts of 4 brands; the high early strength cement, a mixture of equal parts of 3 brands.

14. *Cement Content.* The cement was combined with dry sand in two proportions by weight, nominally 1 to 7 and 1 to 11, giving cement contents respectively of 12.5 and 8.3 per cent by weight of the dry mixture.

15. *Moisture Content.* Usually 5 per cent of water was added to the mixture of dry sand and cement but in some tests the influence of moisture content was studied over the range of 3 to 7 per cent.

16. *Mixing of Batch.* The mixing of the batch and ramming of the test cylinders was carried out in a room controlled at 75°F. and 60 per cent relative humidity. The desired proportion of dry

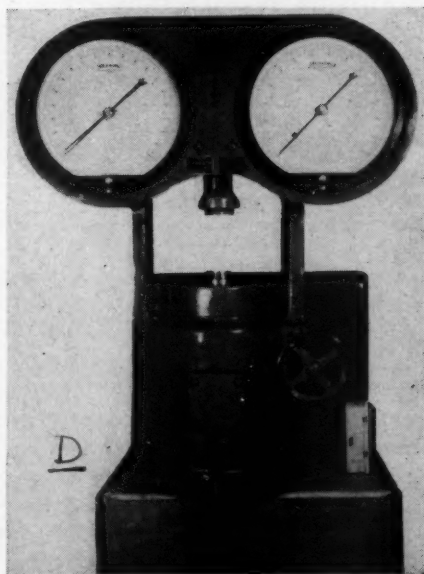


FIG. 3—MACHINE FOR TESTING SET STRENGTH (HYDRAULIC TYPE, CAPACITY 75,000 LB.).

sand and cement were thoroughly mixed in a deep bowl with a slotted mixing spoon. This mixture was then placed in a metal pan, and a crater formed in the center, into which the desired percentage of clean water was poured. The material on the outer edge was turned into the crater within 30 seconds by the aid of a trowel. After an additional interval of 30 seconds for the absorption of water, the operation was completed by continuous, vigorous mixing, squeezing and kneading with the hands for $1\frac{1}{2}$ minutes. During the operation of mixing, the hands were protected by rubber gloves. The mixture was then placed in a glass jar and covered to prevent moisture loss prior to ramming into test specimens.

17. *Time Elapsed Before Ramming.* Usually the damp mixture of sand and cement was rammed into test cylinders within one-half hour after the materials were mixed. In all cases the

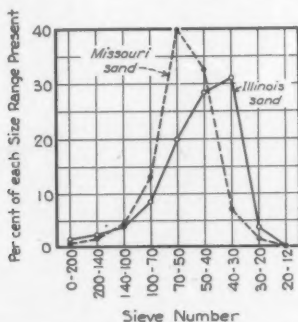


FIG. 4—GRADING AND PARTICLE SIZE DISTRIBUTION OF "ILLINOIS" AND "MISSOURI" MOLDING SANDS.

batch was protected from moisture loss while awaiting ramming. The temperature of the batch was usually 75°F. but in one group of tests it was maintained at 100°F. to simulate possible conditions during hot weather or during prolonged mulling of the mix. In this special group of tests the ramming was delayed for varying periods up to 4 hours. In other groups of tests the ramming of test cylinders was delayed for varying periods up to 6 hours to determine the effect of this delay.

18. *Storage After Ramming.* In general, the test cylinders were placed in a covered container immediately after ramming where they were kept at 75°F. for 3 days to permit hardening without gain or loss of moisture to simulate the conditions to be expected in a closed mold. However, in one group of tests the

storage conditions were varied to determine the effect of drying for one or more days, a condition that might occur in molds which were not closed the entire time.

19. *Accelerating the Hardening.* In one group of tests commercial calcium chloride equal to $2\frac{1}{2}$ per cent by weight of cement in the batch was used to accelerate the development of strength in the test cylinders. It was added dissolved in the mixing water.

20. *Cement-Silica Mixtures.* A group of tests was made in which the sand was combined with $12\frac{1}{2}$ per cent by weight of several mixtures of cement and finely divided silica (Ottawa sand ground to pass the No. 200 sieve). The fine silica present in the various cement-silica mixtures ranged from 0 to 50 per cent by weight of cement plus silica. In this manner the "set" strength

Table 1

STRENGTH AND PERMEABILITY OF CEMENT-FOUNDRY SAND MIXES, AS INFLUENCED BY MOISTURE CONTENT, TYPE AND QUANTITY OF CEMENT, AND CHARACTERISTICS OF SAND.

Test cylinders rammed by 3 blows of standard rammer head, cured moist for 3 days at 75°F., then tested damp for "set" permeability and strength.

Per Cent Moisture	Cement Content, $12\frac{1}{2}$ Per Cent (1:7 Mix)				Cement Content, 8.3 Per Cent (1:11 Mix)			
	Permeability Index No.		Compressive Strength, lb. per sq. in.		Permeability Index No.		Compressive Strength, lb. per sq. in.	
	Green	Set	Green	Set	Green	Set	Green	Set
<i>Illinois Sand, High Early Strength Cement</i>								
3	...	...	...	...	122	122	4.10	395
4	93	88	5.05	690	134	132	2.97	590
5	95	93	4.50	947	128	128	2.35	608
6	99	93	3.30	1080	128	126	1.86	624
7	108	105	2.48	995	...	...	...	...
<i>Missouri Sand, High Early Strength Cement</i>								
3	...	...	...	...	138	136	2.38	360
4	96	96	3.90	590	129	135	1.98	523
5	96	99	3.13	840	119	119	1.81	558
6	98	95	2.52	890	119	124	1.54	540
7	96	102	2.00	900	...	...	...	...
<i>Illinois Sand, Normal Strength Cement</i>								
3	...	...	...	...	114	115	2.78	365
4	94	90	3.22	620	114	115	2.45	416
5	96	96	2.73	720	119	119	2.12	455
6	101	96	2.25	700	112	112	1.90	415
7	93	90	1.89	653	...	...	...	...
<i>Missouri Sand, Normal Strength Cement</i>								
3	79	86	2.62	271	119	121	1.70	264
4	93	91	2.35	460	130	125	1.58	295
5	99	105	1.96	505	135	128	1.37	276
6	102	100	1.69	510	126	124	1.31	231

of the test cylinders could be varied without greatly influencing the "green" strength, the permeability (in green or set condition) or the surface texture. At the same time the amount of cement present and consequently the lime constituents at the mold surface would be reduced by substitution of the fine silica.

RESULTS OF TESTS

21. For the principal results thus far obtained from these studies the reader is referred to the several diagrams and tables accompanying the text. The following brief comments are limited to the general features of the results and the influence of the

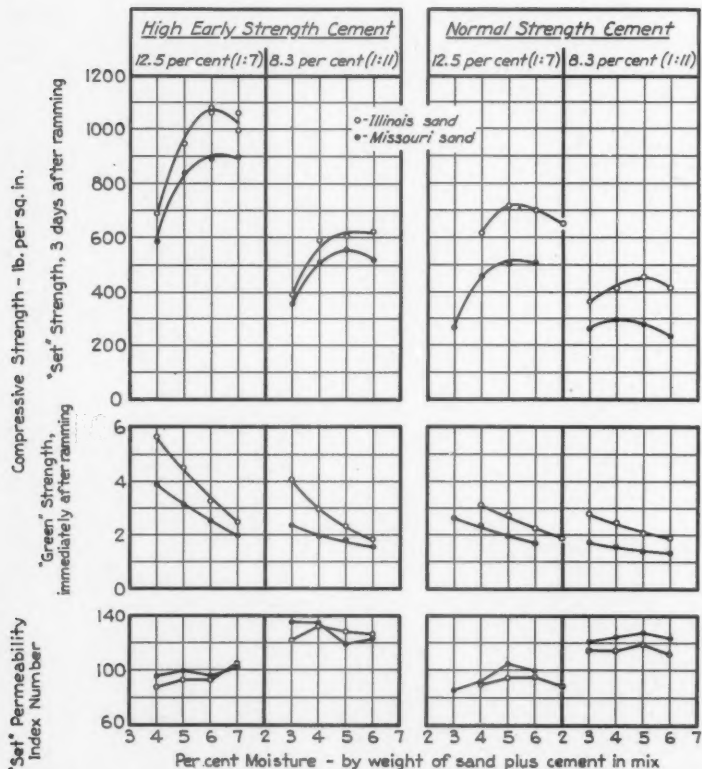


FIG. 5.—EFFECT OF MOISTURE CONTENT AND TYPE AND QUANTITY OF CEMENT ON THE STRENGTH AND PERMEABILITY OF CEMENT-FOUNDRY SAND MIXTURES. DATA FROM TABLE 1.

several factors studied. Designations in parenthesis refer to the appropriate tables or figures.

22. *Sand*. Although similar results were obtained with the two typical silica foundry sands used, the Illinois sand mixtures gave consistently higher green and set strengths than those containing the Missouri sand. Under similar conditions of test, the permeability was the same or nearly the same for both sands.

23. *Cement Content*. (Fig. 5.) For each of the two dif-

Table 2

STRENGTH AND PERMEABILITY OF CEMENT-FOUNDRY SAND MIXES AS INFLUENCED BY AGE AND TEMPERATURE OF MIX.

Test cylinders rammed by 3 blows of standard rammer head, cured moist for 3 days at 75°F., then tested damp for "set" permeability and strength.

All batches were protected from moisture loss while awaiting ramming. Moisture content was constant at 5% by weight of dry materials in mix for both the 12.5 and 8.3% cement contents.

Age of Mix When Rammed, hours	Cement Content, 12½ Per Cent (1:7 Mix)					Cement Content, 8.3 Per Cent (1:11 Mix)				
	Permeability Index No.		Compressive Strength, lb. per sq. in.		Cylinder Weight (Green) grams	Permeability Index No.		Compressive Strength, lb. per sq. in.		Cylinder Weight (Green) grams
	Green	Set	Green	Set		Green	Set	Green	Set	
Illinois Sand, High Early Strength Cement, Mix Rammed at 75°F.										
0.5	95	93	4.50	940	185	128	128	2.35	605	181
1.4	98	90	4.60	950	185	141	143	2.36	660	181
2.5	107	99	4.10	910	185	138	138	2.35	670	181
3.4	116	110	4.69	795	183	138	127	2.30	640	181
3.8	138	138	5.40	395	172	138	138	2.77	470	179
4.5	146	146	5.40	365	173	156	156	3.78	355	175
Missouri Sand, High Early Strength Cement, Mix Rammed at 75°F.										
0.5	96	99	3.21	825	177	119	119	1.81	560	175
1.4	96	98	3.00	845	177	134	134	1.71	565	175
2.5	92	93	2.97	840	177	134	126	1.71	555	175
3.4	107	105	3.08	685	176	138	128	1.55	540	175
3.8	...	...	...	...	...	128	127	1.59	498	175
4.5	114	114	3.25	415	171	128	128	1.80	470	175
Missouri Sand, Normal Strength Cement. Mix Rammed at 75°F.										
0.5	99	105	1.96	502	177					
2.4	92	95	2.09	544	177					
4.4	96	95	2.25	500	177			NO TESTS MADE		
5.7	102	102	2.60	420	172					
6.3	100	98	2.80	337	170					
Illinois Sand, High Early Strength Cement. Mix Rammed at 100°F.										
0.3	102	101	4.88	855	184					
1.0	101	98	5.42	790	182			NO TESTS MADE		
2.0	127	126	7.40	360	173					
3.0	187	179	6.85	52	164					
Illinois Sand, Normal Strength Cement. Mix Rammed at 100°F.										
0.3	95	95	3.26	630	185					
1.7	95	95	3.66	540	183			NO TESTS MADE		
2.1	105	105	4.42	412	180					
3.8	191	185	4.05	68	164					

NO TESTS MADE

NO TESTS MADE

NO TESTS MADE

ferent foundry sands, both the green and set strengths increased directly with the increase in cement content from 8.3 to 12.5 per cent by weight. Although the permeability was reduced from an average index value of 120 to about 90 with increase in cement content, the permeability with the highest cement content tried (12.5 per cent) was still well above the value of 70 which experience indicates is permissible for molds of cement-bonded sand.

24. *Type of Cement.* (Fig. 5.) For the same cement content, mixtures made with high early strength cement showed approximately 50 per cent higher strengths, both immediately after ramming and 3 days after ramming, than those made with normal strength cement. The permeability of the mixtures both green and set was about the same with both types of cement so long as the cement content was the same. However, the strength characteristics of the high early strength cement were such that only about 70 per cent as much cement of this type was required to produce strengths equivalent to those obtained with normal strength cement, either green or set, 3 days after ramming. Hence, due to the lower cement content, mixtures of the same strength were substantially more permeable when made with high early strength cement than with normal strength cement.

Table 3

STRENGTH AND PERMEABILITY OF CEMENT-FOUNDRY SAND MIXES SUBJECTED TO DIFFERENT STORAGE CONDITIONS DURING 3-DAY CURING PERIOD AFTER RAMMING.

Test cylinders rammed by 3 blows of standard rammer head, cured at 75°F. as indicated and tested for permeability and strength 3 days after ramming. Moisture content was constant at 5% by weight of dry materials in mix for both the 12.5 and 8.3% cement contents.

Condition of Storage of Specimens During 3-Day Curing Period after Ramming		Cement Content, 12½ Per Cent (1:7 Mix)				Cement Content, 8.3 Per Cent (1:11 Mix)			
Moist Storage days	Air Storage days	Permeability Index No.		Compressive Strength, lb. per sq. in.		Permeability Index No.		Compressive Strength, lb. per sq. in.	
		Green	Set	Green	Set	Green	Set	Green	Set
<i>High Early Strength Cement</i>									
		(Av.)	(Av.)	(Av.)	(Av.)				
3	0	112	106	4.0	930	131	122	2.6	660
2	1	"	107	"	1120	"	128	"	830
1	2	"	112	"	1005	"	136	"	780
0	3	"	118	"	560	"	127	"	450
<i>Normal Strength Cement</i>									
		(Av.)	(Av.)	(Av.)	(Av.)				
3	0	102	103	2.9	690	141	138	1.8	415
2	1	"	100	"	880	"	140	"	525
1	2	"	107	"	760	"	145	"	470
0	3	"	108	"	360	"	143	"	230

Table 4

STRENGTH AND PERMEABILITY OF CEMENT-FOUNDRY SAND MIXES CONTAINING $2\frac{1}{2}$ PER CENT CALCIUM CHLORIDE, AS INFLUENCED BY AGE AND MOISTURE CONTENT.

Test cylinders rammed by 3 blows of standard rammer head, cured moist for 3 days at 75°F., then tested damp for "set" permeability and strength. All batches protected from moisture loss while awaiting ramming. $2\frac{1}{2}$ % commercial calcium chloride by weight of cement dissolved in the mixing water was used in the batch.

Age of Mix When Rammed, hours	Moisture Content, Per Cent	High Early Strength Cement (12½ Per Cent, 1:7 Mix)					Normal Strength Cement (12½ Per Cent, 1:7 Mix)				
		Permeability		Compressive		Cylinder Weight (Green) grams	Permeability		Compressive		Cylinder Weight (Green) grams
		Index No.		Strength, lb. per sq. in.			Index No.		Strength, lb. per sq. in.		
		Green	Set	Green	Set	Green	Set	Green	Set	Green	Set
<i>Moisture Content Constant</i>											
0	5	104	103	4.39	1172	185	98	95	3.08	890	185
1	"	144	143	6.97	875	178	110	100	3.38	795	184
1½	"	192	187	7.32	198	169	...	...	...	...	...
2	"	243	...	6.94	105	160	111	101	4.18	597	181
3	"	...	...	...	...	...	157	145	4.54	304	172
<i>Age of Mix when Rammed, Constant</i>											
0	4	90	88	5.58	680	180	88	90	3.88	714	181
0	5	104	103	4.39	1172	185	98	95	3.08	890	185
0	6	95	96	3.69	1355	188	100	100	2.56	926	188
0	7	94	88	2.90	1435	192	92	94	2.25	882	192

Table 5

EFFECT OF NUMBER OF TAMPS IN RAMMING ON STRENGTH AND PERMEABILITY OF CEMENT-FOUNDRY SAND MIXES.

Test cylinders rammed immediately after mixing, cured moist for 3 days at 75°F., then tested damp for "set" permeability and strength. Cement content constant at 12.5 per cent (1:7 mix by weight); moisture content constant at 5.0 per cent by weight. Cement, high early strength Portland.

Number of Tamps Used in Ramming	Illinois Sand					Missouri Sand				
	Permeability Index No.		Compressive Strength, lb. per sq. in.		Cylinder Weight (Green)	Permeability Index No.		Compressive Strength, lb. per sq. in.		Cylinder Weight (Green)
	Green	Set	Green	Set	grams	Green	Set	Green	Set	grams
2	117	115	2.99	820	183	114	113	2.32	660	174
3	94	93	4.44	932	185	96	99	3.07	806	177
4	92	89	4.21	1062	188	97	99	2.92	810	179
5	85	81	4.76	1140	191	87	87	3.28	950	181
6	73	73	5.43	1200	193	86	84	3.55	963	182

Table 6

EFFECT OF PER CENT OF FINELY-DIVIDED (— 200 MESH) SILICA ON STRENGTH AND PERMEABILITY OF CEMENT-FOUNDRY SAND MIXTURES.

Test cylinders made with mixtures consisting of 1 part by weight of the cement-silica mixture and 7 parts by weight of foundry sand moistened with 5 per cent of water. The silica content of the various cement-silica mixtures ranged from 0 to 50 per cent by weight of cement plus silica.

Per Cent Silica, By Weight in Cement-Silica Mixture	High Early Strength Cement					Normal Strength Cement				
	Permeability Index No.		Compressive Strength, lb. per sq. in.		Cylinder Weight (Green) grams	Permeability Index No.		Compressive Strength, lb. per sq. in.		Cylinder Weight (Green) grams
	Green	Set	Green	Set		Green	Set	Green	Set	
0	102	102	4.06	946	185	96	96	3.13	690	185
20	102	99	3.71	815	185	97	97	2.94	570	185
30	97	93	3.74	740	185	...	...	...	...	...
40	96	95	3.48	637	185	93	93	2.84	443	185
50	89	88	3.32	572	185	92	90	2.81	346	185

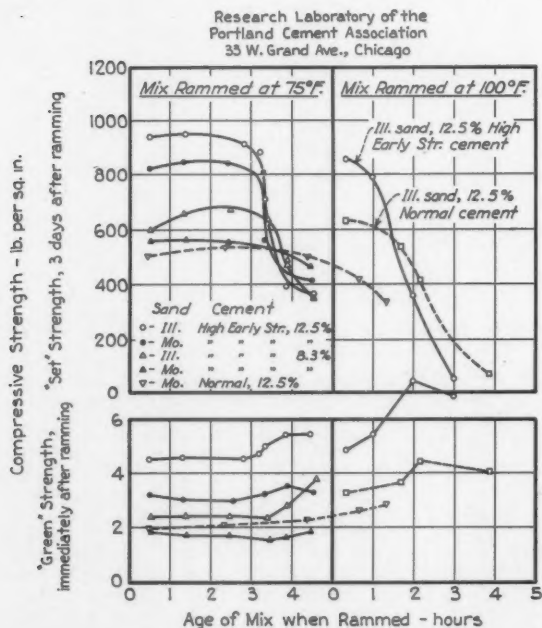


FIG. 6—EFFECT OF AGE AND TEMPERATURE OF MIX ON STRENGTH OF CEMENT-FOUNDRY SAND MIXTURES. DATA FROM TABLE 2.

25. *Moisture Content.* (Fig. 5.) When the moisture content was changed from a total of about 3 to 7 per cent by weight, the green strength decreased rapidly. The corresponding set strength rose rapidly to a maximum at about 5 per cent total moisture content, and then usually decreased gradually as more water was added. To attain both good green and set strength as well as to reduce total moisture present in the mold (to reduce blowing or steaming) it appears desirable to limit moisture content at the time of ramming to 4 per cent for mixtures containing 8.3 per cent cement, and to 5 per cent for mixtures containing 12.5 per cent cement. The permeability of the cement-bonded sand either green or set was not influenced appreciably by variation in moisture content at the time of ramming.

26. *Age and Temperature of Mixture When Rammed.* (Fig. 6.) At normal temperature of 70 to 80°F. the tamping or ramming of a high early strength cement-sand-water mixture can be delayed for approximately 2½-hr. after mixing without materially influencing the green and set strengths obtainable by ramming immediately after mixing, provided no moisture is lost during storage. Sharp reductions in the set strength are indicated if ramming is delayed longer than 3-hr. at 70 to 80°F. With normal strength cement the ramming may be delayed for 4 hours without serious reduction in set strength.

27. At higher temperatures, say 100 to 110°F. such as may be attained during hot weather or during long mulling and mixing, it is not advisable to delay ramming of mixtures containing high early strength cement for more than 1-hr. and those containing normal strength cement for more than 1½-hr.

28. *Storage After Ramming.* (Table 3.) The tests indicated that in order to develop the potential 3-day compressive strength of a cement-bonded sand mixture it was important to prevent moisture loss during the first 24-hr. after ramming. When the cement-bonded mixture was exposed to air immediately after ramming, the loss of moisture during the critical first 24-hr. period resulted in a reduction from the potential 3-day strength of at least 40 per cent with high early strength cement and of at least 50 per cent with normal strength cement. However, when the moisture loss was prevented for 24-hr. or more no marked change in the 3-day strength occurred.

29. It appears, therefore, that a cement-bonded sand mold may be permitted to dry at any period after the first 24-hr. of

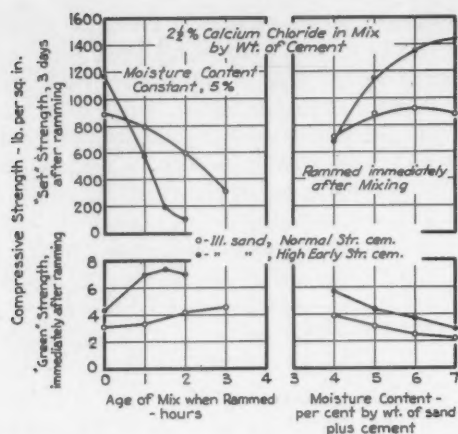


FIG. 7—EFFECT OF AGE AND MOISTURE CONTENT OF CEMENT-BONDED FOUNDRY SAND MIXES CONTAINING CALCIUM CHLORIDE. DATA FROM TABLE 4.

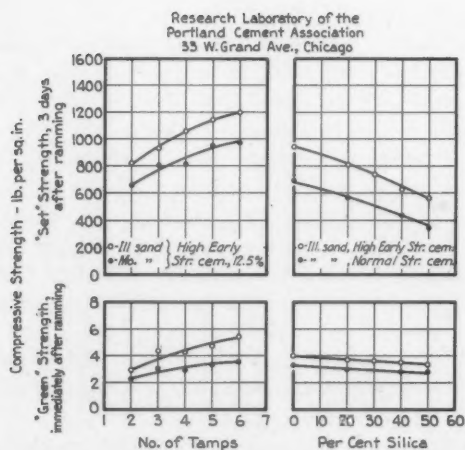


FIG. 8—EFFECT OF NUMBER OF TAMPS AND PER CENT OF SILICA ON STRENGTH OF CEMENT-FOUNDRY SAND MIXTURES. DATA FROM TABLES 5 AND 6.

moist curing without reducing the early compressive strength of the mold surface. Hence, where molds are to be used within a few days, the drying after the initial moist-curing period may proceed either naturally or be hastened artificially to bring the mold surface to the desired dryness for satisfactory results in casting. This drying of the mold surface not only reduces the possibility of blowouts and sudden formation of steam, but also renders the mold more permeable for the escape of gases. In cases where the molds are to stand for more than a week before using, two or three additional days of early moist curing will add materially to the later strength.

30. *Accelerating the Set Strength.* (Figs. 7 and 5.) Somewhat higher set strengths were obtained with the additions of $2\frac{1}{2}$ per cent of calcium chloride to both types of cement (high early strength and normal) when the mixtures were rammed promptly after mixing. However, the strengths decreased sharply as ramming was delayed, particularly with high early strength cement. These reductions in strength were accompanied by corresponding increases in permeability, both green and set, but such increases were not considered to be of sufficient advantage to offset the disadvantage of requiring ramming immediately after mixing.

31. *Cement-Silica Mixtures.* (Fig. 8) By replacing a portion of the cement binder with powdered silica of the same fineness, the "set" strength of cement-bonded foundry sand mixtures can be varied without greatly influencing either the green strength, the permeability either in the green or set condition, or the surface texture of the mold. In this manner the amount of cement present and the resulting lime-bearing constituents at the mold surface can be reduced by direct substitution of the fine silica without altering the smoothness of the mold surface obtained with cement alone.

32. *Ramming of Mix.* (Fig. 8) As might be expected the strength and permeability of cement-bonded sand mixtures both green and set were substantially influenced by more thorough ramming or tamping. The strength increased and the permeability decreased with the number of blows of the tamper. By ramming 6 times instead of 2, the green and set strength of mixtures containing 12.5 per cent high early strength cement was increased 50 per cent but the permeability was decreased from an index value of 117 to 75. However, it should be noted that even with the highest cement content and unusual compaction the perme-

ability of a typical cement-bonded foundry sand was above the permissible value of 70.

RECOMMENDATIONS

33. The results secured in these laboratory studies, together with the observations of foundry practice and the results of experiments carried out in foundries, indicate the feasibility of using portland cement as a binder in foundry molding sand. The following recommendations are suggested as a guide for such use.

34. For the facing of the mold only fresh, clean, well-graded silica foundry sand should be used. The sand should be mixed with about 10 per cent cement and a total of $4\frac{1}{2}$ per cent of water by weight of the dry materials. This damp mixture should be rammed in the usual manner and to the proper thickness. It can be backed up with a mixture composed of cement and a lower grade of sand or other material. Such a facing mixture, when made with high early strength portland cement and protected from loss of moisture for the first 24 hours, will have excellent strength and permeability for foundry purposes, 2 or 3 days after molding, even though dried rapidly following the initial 24-hr. moist period. If normal portland cement is used, the green strength will be lower and a longer curing period and greater age will be necessary to obtain the same set strength. Increasing the amount of normal portland cement would give adequate strength but would bring about an undesirable decrease in permeability and increase the lime constituents at the surface of the mold.

35. The facing mixture may be mixed and rammed in the usual manner but extended mulling should be avoided in order to reduce temperature rise and moisture loss. Mixtures at normal temperatures of 70 to 80° F., should be rammed within $2\frac{1}{2}$ -hr. after mixing if made with high early strength cement, and within 4 hours if made with normal portland cement. Mixtures at higher temperatures, say 100 to 110° F. should be rammed as soon as possible after mixing but not later than one hour.

DISCUSSION

Presiding: JOHN HOWE HALL, Taylor Wharton Iron & Steel Co., Hightbridge, N. J.

MARSHALL POST¹, (*Submitted as written discussion*): I have read Mr. Menzel's paper with particular interest since Birdsboro Steel Foundry & Machine Company has been using the Randupson cement mold process

¹ Vice President, Birdsboro Foundry & Machine Co., Birdsboro, Pa.

for over two years. While, as Mr. Menzel states, there had been for many years suggestions as to the use of portland cement in foundry molds, it has not been until the introduction of the Randupson process that there has been any real use of portland cement as a binder for foundry molds.

In 1934, we heard that a large steel foundry in France was using a new process for making molds, which secured better castings than they had by the old sand mold process. After some correspondence with the French company, Mr. McCauley, the president of our company, and I visited the foundry of the Societe d'Electro-Chimie at Ugine, France, where the Randupson cement mold process was in operation. The Societe d'Electro-Chimie is one of the largest and most progressive metal concerns in France. We saw the process in use in making both large and small castings in iron, steel, manganese steel, and non-ferrous metals. We were so impressed with the results which we observed that we arranged for a license under their United States patents, and on our return commenced converting our No. 1 foundry to use this process.

To determine the results that could be obtained, we started to make some very intricate castings so that we could make comparisons. After we had made a number of these castings, we had established in our own minds that we could produce castings of a quality by this process that were superior to castings which we had produced by the various sand mold methods. Experience has fully borne out our first impressions of the process and we are getting even better results than we had hoped to secure. We are now regularly producing castings of a quality which we could not possibly have made by the conventional sand molds. At the present time we have practically discontinued the use of sand molds in what was formerly our dry sand shop and are there making most of our castings by the Randupson cement mold process.

Before taking the license under the United States patents, we had our attorneys thoroughly investigate the patent situation and they reported that the French company had a strong patent situation, both in the United States and abroad. The Moldenke book on the "Principles of Iron Founding," referred to in Mr. Menzel's paper, as well as other early suggestions of the use of Portland cement in foundry molding, were considered by the examiner in the United States patent office, who granted the three Durand patents which cover the Randupson process.

Since we were willing to spend the money to demonstrate the application of this process to American foundry practice, the Societe d'Electro-Chimie has appointed us sole agents for the granting of licenses in the United States and Canada. Representatives of the leading foundries in the United States and Europe have visited our plant, and a number of foundries are now operating the Randupson process with excellent results.

As most of you know, our foundry has been open to visiting foundrymen. Since the news of our success has traveled through the industry, we have had many visitors to whom we have been glad to demonstrate the process and give full information about it. About a year or two ago, Mr. C. E. Sims, who collaborated with Mr. Menzel in the work described in the paper, visited our foundry, and we gave him formulas which we employ in making our cement mixes. It is very interesting to note that

the procedure outlined in the paper very closely resembles what Mr. Sims observed at our works.

The process and the formulas which we use in the cement mold process in our plant are covered by three United States letters patent owned by Societe d'Electro-Chimie, who has patented the process in Canada, as well as in France, Germany, England and other industrial European countries.

CHAIRMAN HALL: I am glad that Mr. Post has put the discussion before you in the form in which he has, because we all know about the work that has been done at Birdsboro. A lot of us have been there, and we might as well have the thing recognized. Then we can discuss the points brought out in the paper. The paper is open for further discussion from the floor. How about it, Mr. Sims?

C. E. SIMS²: My connection with this work of Mr. Menzel's has been of a very minor nature. The company I was with several years ago investigated the cement mold process and did some experimental molding. In connection with this work, we had a very natural desire to learn as much as we could about the properties of cement. The Birdsboro people were very kind in giving all the information they had available, but one never has too much information about anything, and in an effort to see if there were some points that could be cleared up, we decided to go to experts on cement, and the ones we naturally thought of were the people who were doing research work in cement—the Portland Cement Association. Mr. Menzel is a personal friend of mine, and I suggested to him that here might be a very good field for their activities in disseminating knowledge regarding cement which would be useful to foundries who had considered adopting this process. It is needless to say one purpose of this organization is to extend the use of cement by any means that are legitimate.

I want to congratulate Mr. Menzel on this presentation. He is not a foundryman, and is not versed in foundry technique. I gave him what information I could in regard to the principles that were necessary to keep in mind when undertaking a study of this kind. I think he has done an excellent piece of work in showing the possibilities, the limitations, and the possible pitfalls that are to be avoided. The avoidance of pitfalls should accelerate the use of cement as a bonding material. Of course, the paper does not cover any direct foundry application; it merely considers the cement bonded sand as a structural material.

I do not believe I could really add anything to the data in the paper. I think it speaks for itself. I can assure you the work was quite thoroughly done, and the information is to be considered as reliable.

CHAIRMAN HALL: The chairman notices with a great deal of interest the desirability of storing the molds in a moist atmosphere for 24 hours and then about two days in dry air. Has it been figured out how that might be done without having a sort of greenhouse to do it in?

MR. POST: When something new develops there is apt to be a great difference of opinion. We have all gone through the core oil stage. We did not work that out in a year or two. Now, in this process, we are finding out each day more things about it, the details of which we could

² Supervising Metallurgist, Battelle Memorial Institute, Columbus, Ohio.

talk about forever, I suppose. As I stated a moment ago, there might be differences of opinion on practices of our company. At our plant we govern the amount of time upon the job. There are a lot of variables.

CHAIRMAN HALL: Has moist storage been tried to any extent?

MR. POST: We have tried any number of different plans and it does not seem to make a lot of difference, just so we give the molds time to properly cure.

CHAIRMAN HALL: I know Mr. Aptekar has some views on this subject.

R. E. APTEKAR²: My views are founded on the little experience we have had with cement molding. We are very much indebted to Mr. Post and his entire organization for the fine courtesies they exhibited to our men who went through the plant, and the work they aided us in doing in making tests. We saw the most remarkable results obtained. No one who has seen the process in actual operation can possibly doubt for one moment the very great superiority of castings that are produced by this process.

I would like to contribute one line of thought to this discussion. That is a bit of information on the thermal behavior of this material in actual use. There appears to be a 3-stage thermal reaction on pouring.

The first stage is a dehydration stage. During the interval when this occurs, the sand mold loses its strength very rapidly and tends to spall slightly and wash. That is true only during the initial heating-up period. That period in actual practice is a relatively short time, and evidently presents no great danger of causing defective castings at all, but it does involve the concept of properly heating the mold with sufficient rapidity to prevent any protracted period of heating up the mold.

The second stage, incipient fusion which follows quickly after the first one, is subsequent to dehydration. During this period the best type of cement molded casting is obtained. The portions of the castings that reach that stage are extremely smooth. The surface is absolutely unaffected. There is no penetration, and there is no tendency for any gas evolution at this stage. That is the ideal stage to develop in all parts of the casting.

The third stage, chemical attack of cement on sand, occurs practically only at the gate areas, where great heat input is evident. During this third stage, the combined water in molecular combination with the cement tends to become liberated, and in doing so, this water has a tendency to cause slight surface deformations and occasionally an internal gas bubble.

That brings us to the point of the remarkable success that the Birdsboro Foundry and Machine Company has had with this process which has been due to a large extent to their handling of the gating, and their ability to distribute the heat input properly throughout the various portions of the casting, to avoid retaining the first stage of this 3-phase reaction; and further, to avoid the third stage, which is undesirable. As I said before, I think they have done a fine job of learning the proper gating and handling of this material in that respect.

D. C. ZUEGE³: We are one of the companies that had some of our men go through the Birdsboro plant and, as others have said, we were much

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³ Technical Director, Sivyer Steel Casting Co., Milwaukee, Wis.

impressed with the character of the castings which we saw there. However, in a small casting steel foundry, in which the castings are made largely in green sand, we found some limitations to the process. That is, we do not make a large number of dry sand castings and we do not find many of the advantages which the dry sand shop would find through the use of the cement process. However, we do want to say that the Birdsboro castings that we saw were very excellent surfaced castings.

A. W. GREGG⁵: I was in Cincinnati about two months ago and I visited the Sawbrook Steel Castings Co., where the cement process is being used. They are making beautiful castings. I asked Mr. Wright, who is the general superintendent, if the process did not require a great deal more floor space and he said, "Sure, it does." He was building an addition to his shop to take care of this. This particular point has not been emphasized, and that is why I am bringing it up here. However, Mr. Wright showed me figures which tend to prove that the depreciation cost of his additional building is considerably lower than the cost of drying the molds. Mr. Wright is certainly making some beautiful castings with the cement process. His work is small to medium, and includes blank gears which were formerly made in dry sand.

MR. APTEKAR: In this connection with the point of floor space involved, I should like to recommend to those present that they read an article which appeared very recently in the transactions of The Institute of British Foundrymen which concerns a Randupson foundry recently organized, in which the storage has been distributed in a vertical direction, rather than spreading it out. I want to come to the defense of the process to the extent of saying storage is purely a matter of the mechanical handling of molds, such as possibly on racks, or some other means that will adequately take care of it.

MR. POST: I would like to say one thing about that. We have had some experience along that line. We find we have more capacity in our shop than we had formerly, because we can rack cement molds the same as you would rack brick. The space formerly used for drying ovens makes an excellent storage area. It is the actual experience of shops where they have adopted this process 100 per cent that they can make more molds, due to their being more compact, than they can with the conventional type of mold. It has been my experience that flask trunnions and flanges take approximately 15 to 20 per cent of regular molding floor space.

MAJOR R. A. BULL⁶: Mr. Chairman, I think probably many people in the audience are thinking, as I am, that this paper is unusual, because it seems to relate definitely to a process that is covered by patents, but makes no reference to those patents. If I am wrong about that, I want to be corrected. Apparently, the paper was prepared partly as a result of information that was obtained in the plant which controls the patents in the United States.

⁵ Whiting Corp., Harvey, Ill.

⁶ Consultant on Steel Castings, Chicago, Ill.

I would like to say, as far as the attitude of the Birdsboro Steel Foundry and Machine Company is concerned in respect to the hospitality that has been referred to by Mr. Post, that you do not need to discount that. I know, personally, that the company has been extremely liberal in showing everything about the process to anybody connected with a steel foundry who wants to come and see it. I think we would all be better off in the long run if all our visitation policies were followed along the same line. I would also like to say I have had the opportunity of spending a little time in the Birdsboro plant to see the molds being made and poured, and I have seen quite a number of castings after they have been made. I can say that certain types of castings, which I have seen made by this process, had superior surfaces, as compared to any castings of similar nature which I have ever seen made in sand molds.

Every process has its limitations, whether we recognize them at first or not. Dry sand has its place, green sand its place, oil sand its place, pitch its place, and so forth. Sometimes, though, we become particularly interested in developing a new process and get bitten by some bug that causes us to think that a method has opportunities beyond its limitations. I am convinced that the Randupson process has its limitations, and it would be ridiculous to assume that it does not. It seems to me that where it fits, it does a swell job. Incidentally, I wish to state that I have never had any commercial connection with those who control the patents applied in using the Randupson process.

I am not competent to discuss the economic side, as compared to the cost of making dry sand molds.

C. W. Briggs¹: Contrary to Major Bull's statement that, "apparently, the paper was prepared partly as a result of information that was obtained in the plant which controls the patents in the United States," I should like to point out that Mr. Gezelius and I published a paper* in 1933 in which we studied the uses of cement bonded sand, the moisture contents necessary and the permeability and strength that could be obtained. This paper would have furnished all the information Mr. Menzel needed as a source for preliminary information. Personally I see nothing unusual in writing about a process covered by patents.

There is also a point in connection with the paper I have been wondering about. Why is it necessary that such high strengths, around 1,000 and 1,500 pounds per square inch be developed? I would like to know why this seems to be important? In the work that has been presented, the time of storage and the various amounts of cement that were added were all aimed at keeping the strength up as high as possible. I would be very much interested in knowing why we want to obtain such high strength.

There is another point that I would like to be more fully instructed upon. I have heard various ones exclaim over the beautiful and marvelous castings made by this process. This process has absolutely no effect on the physical laws of solidification and contraction and, therefore, has no claims over any other method in producing internally sound cast-

¹ Naval Research Laboratory, Anacostia, Washington, D. C.

* *European Synthetic Molding Sands*, C. W. Briggs and R. A. Gezelius, Journal American Society for Naval Engineers, November 1933, page 462.

ings. Personally, I am more interested in the internal aspects of a casting than I am in its surface.

CHAIRMAN HALL: This paper does not cover in any way the actual production of castings, but describes the properties of cement sand mixtures of various kinds that you will get when you handle the cement and sand in different ways. I do not understand that this is anything more than a preliminary survey, showing the properties of these materials. Whether it is desirable to get up to those high strengths or not, as I understand Mr. Menzel's paper, is a matter not yet reached by the author. He is just showing you that, under conditions described, you will obtain certain strengths. Of course, this audience, being almost entirely made up of foundrymen, goes way ahead of the paper and may be prompted to ask, "Now, if I use such and such a mixture, what affect will it have on my castings?" Mr. Menzel, would you like to reply to Mr. Briggs' question now?

MR. MENZEL: Mr. Chairman, I do not see how anyone could get the impression by reading this paper that this use of cement is new. As mentioned in the paper, cement was used in foundry practice 40 years, or more, ago. Furthermore, cement has been used much longer than that to bind particles of sand together. You all know that. Portland cement mortar—you have heard that dozens of times. Now, it is interesting to note that the recent use of cement in foundry sand molds, did not develop until high early strength portland cements became available.

We could not ignore the receipt of so many inquiries on, "How are we going to use portland cement as a binder in foundry molding sands to best advantage?" If we can show that portland cement has possibilities for foundry use, it seems to me that if anybody may have valid patents, he should be glad to have us develop this use further.

There is no attempt to steal anybody's thunder. This paper simply presents what properties you can get with a mixture of silica sand and portland cement in different proportions, and to show how moisture and other factors can affect these very appreciably.

I do not know, and I don't think some of you know, what final set strengths you want in the mold. I have not seen anything published on the subject. Moreover, I do not think anyone knows definitely what the green strength should be. We have merely presented information that you can use as you see fit. Those who are interested in developing this process will still be able to find something of interest in the paper.

J. C. PENDLETON^{*}: Mr. Briggs was speaking about the strength of the material and questioned the necessity of a mixture so strong. I might state in this connection that our company has manufactured castings of all types—of iron, brass and steel, using the Randupson process introduced by the Birdsboro Company. I could not understand why it was necessary to use so much cement, and I tried reducing the percentage amounts. I found you needed approximately 12 per cent to give you the best results; smaller amounts would not stand the erosion or the temperature of the steel. Concerning hot tears. I remember very well a very difficult steel

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manifold we had to make. We manufactured the manifold and had considerable trouble with hot tears. We made all the cores in green sand, but we continued to have hot tears. And simply because we wanted to see what cement really would stand, we manufactured all the cores in cement. The castings with the cement cores—and this sounds unreasonable—turned out better than any of the castings we had made before, using all green sand cores.

We have been using this cement process for about a year and a half, and there is a lot that can be said about it and a lot to learn about it for anyone who attempts to make castings by using it. Like any other system of manufacturing castings, there are problems you must work out yourself. You could not follow this paper as outlined and proceed to manufacture good castings from the start, without running into a great many disappointments and defective castings.

MR. SIMS: The suggestion has been made several times from the floor that Mr. Menzel's paper was based partly on information received from the foundry controlling process patents and which was not otherwise available. In all fairness I feel impelled to correct this impression. To my knowledge the author started only with information generally available in the technical and patent literature. Mr. Post has stated that he gave out information freely to all.

The fact that Mr. Menzel experimented with low cement contents was inevitable from an economic standpoint alone. And if his final recommendations are in the same range as that used by those who have had experience, these data should be received as a welcome confirmation of their own work.

CHAIRMAN HALL: It is fundamental data which we need, on what we will get with different mixtures of cement, sand and water, and the properties that we will secure. It is up to us as foundrymen, as it has been pointed out, to figure out how much strength we want in a mold.

P. E. MCKINNEY*: My hopes were that we could undertake a more detailed discussion of some of the excellent results that were presented in this paper, purely from the angle of the physical and chemical reactions that take place when you mix cement, sand and water in these varying proportions. Personally, I was very much impressed with the remarks made by the speaker on the effect of curing, not necessarily on strength, but from the angle that moist curing may develop more of the available properties of the cement as a binder, than if drying is allowed to go along in the air. Any of those who have done any structural concrete work, know that for the very best properties you do not accelerate the early stages of the setting of a concrete structure. I would be curious to know, and I believe it would be a matter that should be studied further, as to what connection that condition of moist curing would have with the condition cited by Mr. Aptekar, particularly the third phase, when you begin to get surface fusion. We know, as he pointed out, that by clever gating and heading, it is possible to avoid local hot spots. From the observations that I have had a chance to make on the general behavior of cement and sand, that is one of the serious problems. You may get a

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casting which is perfect over 90 per cent of the area, but due to the particular shape of that casting, it has been necessary to gate at one or two spots and to pass 30 or 40 tons of metal over a certain area in that mold face. The rough condition of that area will sometimes counterbalance the excellent condition of the other areas that have not been subjected to severe erosion and excess temperature.

It certainly seems to me that a study of the possible effect of curing would be quite worth while, having in mind, as the author has pointed out, that free lime in the surface is detrimental. Now, certainly with the accelerated setting the tendency would be to have more free alkali at those spots than if you were to have a more protracted setting-up period. I had hoped we might get a little discussion of that feature.

MR. MENZEL: All I would like to say is that you can choose for yourselves just what cement content and what moisture content you want to use. These will depend upon what is necessary for good castings, whether they be steel or gray iron, malleable or some non-ferrous metal. There is no intention to try to load the sand with cement. I think if you will even read the paper over casually that you will be impressed with the idea that we do not want to put too much cement in the sand. It does appear that there is a definite field for cement as a binder in foundry practice, and it is surprising that it has not been used more frequently in the past. But, as I said before, the recent interest in the use of cement for foundry molds very probably is due to the development of high early strength cements. During the presentation, you will remember, we talked about high early strength cements more than about normal strength cements. The reason is that there are advantages in the use of high early strength cement. If you are working for a given strength, you would use less high early strength cement than normal strength cement, and would get greater permeability. This is in the right direction; it is all to your benefit.

I hope that the paper will answer, in part, the many inquiries we have received as to how best, from the foundryman's point of view, to use cement for this purpose.

Production of Pressure Tight Castings in 30 per cent Cupro-Nickel

By T. E. KIHILGREN,* BAYONNE, N. J.

Abstract

A method of foundry procedure for the production of pressure tight castings in 30 per cent cupro-nickel is described. It involves melting under slightly oxidizing conditions followed by oxidation of the melt, and subsequent deoxidation, (with both silicon and manganese in suitable amounts added 3 to 5 minutes before pouring). The simple 30 per cent nickel-70 per cent copper alloy, treated with silicon alone, while adequately killed, is sluggish to pour due to a tendency to form a tough film or envelope about the stream of molten metal. This tendency is neutralized by the co-presence of manganese, one per cent of the latter being quite adequate to impart excellent fluidity with silicon ranging from 0.25 per cent up to at least one per cent. Sound pressure tight castings are readily obtained by the simultaneous addition of one per cent of manganese and as little as 0.25 per cent of silicon. However, higher silicon contents (0.25 to 0.75 per cent) may be used in conjunction with one per cent of manganese for the purpose of improving the strength properties while still retaining quite high ductility. Lead is a decidedly dangerous impurity in silicon content cupro-nickel causing "leakers" and hot cracking, and should be virtually absent. The effect of other elements such as zinc, tin, iron, etc. on the castability and physical properties is developed briefly in the paper. The method of feeding the castings as well as the pouring temperature has a marked effect on the quality of castings. Photographic illustrations of castings made under various conditions from 150 to 250 lb. experimental foundry heats are included to demonstrate the importance of controlling these factors.

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INTRODUCTION

1. In recent years, 70:30 copper-nickel alloy has found increasing acceptance in various applications where excellent resistance to sea water corrosion is required. The now well recognized anti-fouling properties and practical freedom from pitting and water-line attack under such conditions make this alloy particularly attractive.

2. Outstanding applications of the alloy in wrought form are for marine condenser tubes and salt water lines such as fire lines and sanitary lines. Other applications are developing, including condensers in oil refineries and in power stations at seaboard locations, and sheathing for life boats.

3. Naturally, in conjunction with the increased use of wrought 70:30 has come the need for cast fittings, such as couplings, tees, ells, pump bodies, valve bodies, etc., all of which must be sound and pressure tight.

4. In addition to the above field, 30 per cent cast cupro-nickel may find application under service conditions where physical properties or corrosion resistance intermediate between those of nickel silver and various high nickel content alloys are appropriate.

5. In passing, it may be pointed out that there is no sharp line of demarcation between the cupro-nickels and the nickel-silvers. We may consider nickel-silvers to be essentially cupro-nickels modified with zinc, and further, for pressure work, with tin and lead. For our purposes, we may arbitrarily define the cupro nickels as copper-nickel alloys nearly or completely free from these modifying elements.

6. Inasmuch as the cupro-nickels are used primarily for their corrosion resistance, cast fittings should of course approach the wrought material in corrosion resistance, and therefore in purity, as closely as is consistent with suitable castability and physical properties. This suggested the need for more systematic information on the casting properties of the cupro-nickels before a satisfactory compromise between purity of casting composition and reasonable freedom from sensitivity to foundry conditions could be safely made.

7. In the present paper, we shall first discuss a foundry procedure which has been found to give excellent results, and later deal briefly with the effect of various elements singly and in combination on the castability and physical properties of the basic 30 per cent nickel—70 per cent copper alloy.

PART I—FOUNDRY PROCEDURE FOR 30 PER CENT CUPRO-NICKEL
Casting Composition

8. Excellent castings can be made in 30 per cent cupro-nickel simply by the simultaneous addition of manganese and silicon in suitably controlled amounts to the melt a few minutes before pouring. As far as soundness alone is concerned, the addition of 0.80 to 1.0 per cent manganese and 0.20 to 0.30 per cent silicon will be found adequate under reasonably good melting conditions. However, a somewhat higher silicon content may be employed where higher physical properties are required, and we have found it useful to aim for about 0.50 per cent silicon in the casting. A small addition of magnesium (0.025) per cent) is also made just before pouring, in cases where some sulphur pick-up is probable.

9. Iron is not essential to the production of sound castings, the manganese alone being quite adequate to impart excellent fluidity and castability to the silicon content mixture. Under normal foundry conditions it may be difficult to keep iron out of

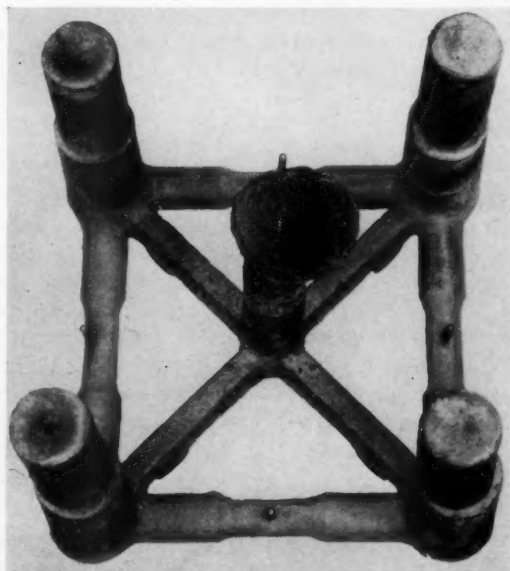


FIG. 1—TENSILE TEST CASTING

the melt and in small amounts it may be useful in increasing the strength and elastic properties at a given silicon content without affecting the ductility adversely. Iron is, however, somewhat objectionable from a corrosion angle, particularly in marine applications, and for this reason should be kept as low as is practical. Its inclusion in the mixture given below represents a compromise between purity and practical foundry considerations.

10. For most of the foundry studies involving 150 to 175 lb. oil fired crucible heats and 250 lb. indirect arc rocking type furnace melts, attention has been centered on the following mixture:

30.0 per cent Nickel
0.5 per cent Silicon
1.0 per cent Manganese
1.0 per cent Iron
balance Copper

11. Cast in the four bar pattern, shown in Fig. 1, the properties of Table 1 are representative of values obtained in 150 to 250 lb. foundry melts.

Table 1

Composition				Tensile Strength Psi	Yield Point 0.5% Ext.	Elong. In 2 in. %	Charge Melted In Lbs.	Furnace Type
Ni %	Si %	Mn %	Fe %	lb. per sq. in.	lb. per sq. in.			
30.19	0.50	1.11	1.03	63,200	31,500	39.0	250	Rocking Electric
30.02	0.39	1.03	1.10	60,000	28,250	37.0	250*	Rocking Electric
30.23	0.50	1.10	1.29	66,500	35,000	35.0	150	Oil Fired Crucible

*40% scrap.

Raw Materials

12. Assuming the melting equipment to be reasonably efficient, it is preferable to use virgin metals (electro-nickel and electrolytic or fire refined copper of good quality) for the base charge plus a reasonable amount of remelt gates and risers (30 to 50 per cent). It is highly important that the raw materials constituting the charge be *lead-free*, as this element is decidedly detrimental in silicon content cupro-nickel castings.

13. Silicon and manganese may be conveniently added as refined silicon (97 per cent Si) and low carbon manganese metal. The use of 2:1 or 50:50 nickel-copper shot for introduction of

nickel will be found desirable when the melting equipment is somewhat inadequate with respect to temperatures attainable.

14. Up to 50 per cent of clean scrap (remelt gates and risers) may be included in the charge satisfactorily and under some conditions higher proportions may be used to clean up accumulated scrap. Incidentally, the desirability of using *clean* scrap should be emphasized and it should be preferably sand blasted to remove foreign matter. For normal operation an average figure of 40 per cent scrap in the charge should be satisfactory. The use of turnings and borings is not advisable, as undesirable impurities such as sulphur may be introduced due to the presence of cutting oil, and lead contamination from admixture of other alloys is a hazard.

Melting Equipment

15. Thirty per cent cupro-nickel can be quite satisfactorily melted in crucible and electric furnaces. Oil fired crucible furnaces are preferred to coke fired, because they insure more rapid melting and greater ease in meeting the pouring temperature requirements. A low sulphur-content fuel oil (0.60 per cent max.) should be used. Induction and indirect-arc rocking type furnaces, as well as the direct-arc may also be used, a suitable slag being desirable in the latter instance.

Melting and Deoxidation Procedure

16. The succeeding remarks will apply particularly to metal melted in oil fired crucibles (150 to 175 lb. charge) although it may be remarked that the same procedure has been found to work well in 250 lb. melts made in the indirect-arc rocking type furnace and in 35 to 45 lb. induction furnace melts.

17. Usually the nickel and copper (and iron if it is to be present) are charged first and melted down, using a slightly oxidizing flame. The melt is then deliberately oxidized with nickel or copper oxide ($1\frac{1}{4}$ ounces of the former or $3\frac{1}{2}$ ounces of the latter per 100 lb. of virgin metals). The addition may be put in a paper bag and dropped into the melt and stirred in vigorously. This step may not always be necessary, sufficient oxidation probably occurring through the introduction of the scrap to remove hydrogen and other reducing gases from the melt. In any event, it will not be harmful as an addition.

18. After the oxidation treatment, the remelt gates and risers may be added and melting resumed.

19. About 3 to 5 minutes before pulling the crucible (or tapping the heat) the manganese and silicon are added simultaneously, as 97 per cent manganese metal (low carbon) and refined silicon. If the charge consists of new metal, about 1.20 per cent manganese and 0.55 per cent silicon ($1\frac{1}{4}$ lb. of manganese and 9 oz. of silicon per 100 lb. of melt) should be added to obtain the one per cent manganese and 0.50 per cent silicon levels desired in the finished casting.

20. When remelt gates and risers are included in the charge, allowance will have to be made for the silicon and manganese introduced with the scrap, in arriving at the amount to be added in finishing off the melt. The addition of $1\frac{1}{4}$ lb. of manganese and 9 ounces of silicon per 100 lb. of *new metal* in the charge, should work out satisfactorily. The necessary adjustments in this direction, however, will depend on the conditions involved in the individual foundry and can be readily determined.

21. The addition of 0.025 to 0.05 per cent of magnesium immediately on pulling the crucible is a useful precaution to take care of any sulphur pick-up which may have occurred in the melt-down.

Cover

22. The experimental foundry heats were made without a cover, and gave metal of consistently good quality. Under some conditions of melting it may be advisable to use glass covers.

Pouring

23. As in the nickel silvers, the castings should be poured fairly rapidly, and it is helpful to choke the gate in order that oxides and dirt may be floated readily in the sprue. With suitable melting equipment and moderate sized castings 150 to 175 lb. charges are readily handled in the crucibles. Under less satisfactory melting conditions or for light castings requiring quite high pouring temperatures, it may be desirable to limit the charge to 100 lb.

24. A pouring temperature range of 2500 to 2650° F. will, in general, be found satisfactory. Moderately heavy castings should be poured on the low side and light castings should approach 2650° F.

Molding Procedure

25. It is essential that 30 per cent cupro-nickel castings be generously fed. Where possible it is desirable to gate directly into the risers so that they will receive the hottest metal at the end of the pour. The riser should feed directly into the heavy sections of the casting whenever possible. The location of the risers is important and should be given considerable attention. These matters will be discussed at greater length in a subsequent section.

Molding Sand

26. The molding sands should be refractory and of fairly high permeability (40 to 60 A.F.A.). The castings illustrated in this paper were made with a synthetic sand (14 per cent clay, balance silica sand) of about 80 permeability and 5 per cent moisture content.

27. This sand is considerably more open than is necessary, although rather good surfaces can be obtained by dusting or brushing dry graphite on the mold surface; this does not interfere seriously with the venting properties of the sand, and yields castings of satisfactory appearance. For castings of moderate size a sand of 40 to 60 permeability and 4.5 to 5.5 per cent moisture content should be suitable.

Cores

28. These should be moderately soft and well vented and should collapse readily to prevent excessive stressing of the casting on contracting about the core. Either a graphite or a silica flour core wash may be used for a core facing.

Summary of Foundry Procedure

29. The steps involved in the production of 30 per cent cupro-nickel castings are summarized below. While the manganese and silicon additions indicated therein aim for about 0.5 per cent silicon and one per cent manganese, it should be noted that sound castings can be produced with as little as 0.25 per cent of silicon in conjunction with one per cent of manganese, while the addition of up to one per cent silicon (with one per cent of manganese) for the purpose of increasing the strength and elastic properties will cause no serious loss in castability.

(1) Melt down copper and nickel (and iron, if it is to be present) using a slightly oxidizing melting atmosphere.

(2) Oxidize melt with nickel or cuprous oxide ($1\frac{1}{2}$ oz. or $3\frac{1}{2}$ oz. per 100 lb. of melt, respectively. Stir into melt vigorously. This step, under some conditions of melting, may not be necessary, and experience will indicate whether or not it should be included in the melting procedure.

(3) Add remelt gates and risers (clean and reasonably free of sand) and continue melting. Avoid the use of turnings and borings.

(4) Three to five minutes before pouring, add simultaneously $1\frac{1}{4}$ lb. of manganese metal and 9 to 10 oz. of refined silicon per 100 lb. of new metal in the charge (aiming for one per cent residual manganese and 0.50 per cent residual silicon in the casting). The desired silicon content will depend on the properties expected; the 0.50 per cent silicon content suggested happens to confer fairly good strength properties while retaining a high degree of ductility, and excellent castability.

(5) Add $\frac{3}{8}$ to $\frac{3}{4}$ oz. of stick magnesium per 100 lb. of charge, after pulling the crucible. The magnesium must be plunged below the surface to be effective.

(6) Pour at 2500 to 2650° F. into well vented molds, generously gated and fed. Castings of moderate to heavy section should be poured at or below 2575° F.

(7) Use a refractory open sand of 40 to 60 permeability and 4.5 to 5.5 per cent moisture content and moderately soft cores which will collapse readily.

30. The above procedure is not inflexible and may require modification to meet the conditions of the individual foundry. It has however been found to give good results repeatedly.

PART 2—INFLUENCE OF GATING AND POURING TEMPERATURE ON QUALITY OF CASTINGS

31. As in other alloys, even assuming the melting and de-oxidation procedure to have been quite satisfactory, the castings may still be defective, leaking on hydraulic tests. Incorrect pouring temperatures or faulty gating and heading, or a combination of both may well be responsible for such casting failures and real effort to control these factors will be well repaid. The castings used to illustrate these points were cast from 150 to 175 lb. crucible heats and 250 lb. indirect arc furnace heats in a 30 per cent Ni—1 per cent Mn—1 per cent Fe—0.50 per cent Si mixture.

32. Fig. 2 illustrates the effect of proper and improper location of gates and risers. Casting *B* has a pronounced shrink, the reason for which is obvious, the gate being so located as to be unable to feed the heavy section through the constricted neck. Casting *A* poured at the same temperature is so gated as to feed directly into the heavy sections. The former leaked and the latter was tight at 1000 lb. per sq. in. fluid pressure.

33. Fig. 3 is a larger quick opening gate valve (3 in. IPS) gated similarly to *A* of Fig. 2. This casting can be cast pressure

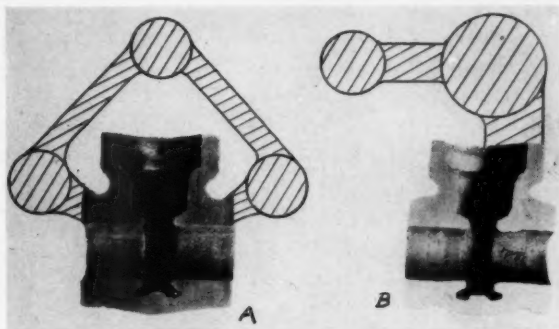


FIG. 2—VALVE BODIES CAST IN 30% CUPRO NICKEL SHOWING EFFECT OF VARIATIONS IN GATING AND HEADING.



FIG. 3—QUICK OPENING 3 IN. GATE VALVE BODY.

tight with this gating when poured between 2500 and 2600° F. Fig. 4 shows a split section of this type of casting with the gating schematically represented. Sections *a*, *b* and *c* are from three castings poured over the range of temperatures indicated, the location of the section being shown by the dotted line, A, A¹.

34. Section *a*, from a casting poured at approximately 2750° F., shows excessive shrinkage, and leaked in this area. Section *b*, from a casting poured at about 2665° F. was pressure tight, but does show some sign of shrinkage in the critical section A, A¹. Section *c*, at 2585° F., was quite satisfactory and was pressure tight. With this gating, pouring temperatures ranging from 2500 to 2600° F. should yield quite satisfactory results, but it is probably preferable to remain below 2575° F.

35. Obviously, one might expect that provision for feeding this critical portion more completely would reduce the sensitivity of the casting to pouring temperature. Such a gating is shown in

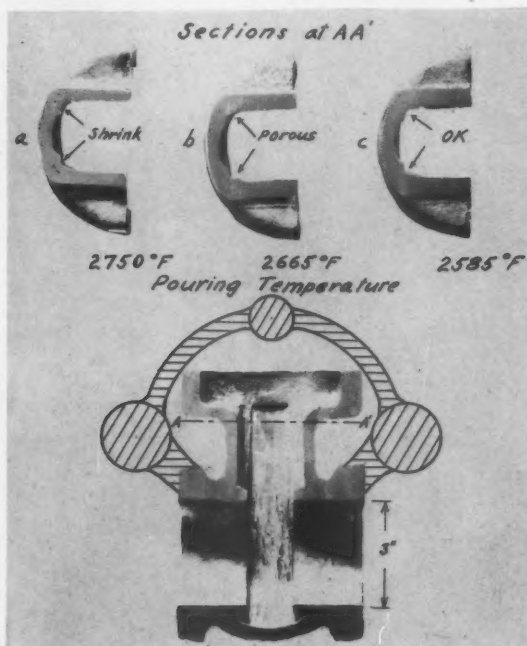


FIG. 4—QUICK OPENING 3 IN. GATE VALVE—SHOWING SECTIONS FROM CASTINGS POURED AT VARIOUS TEMPERATURES.

Fig. 5 and yields sound castings over a somewhat wider range of pouring temperatures.

36. In Fig. 6 is shown a longitudinal section of this valve with gating indicated diagrammatically. The cross section at the critical region is quite free of any suggestion of shrinks. This casting was poured at about the same temperature as section *b* of Fig. 4 (2650° F.). The superiority of the more completely fed casting is apparent.

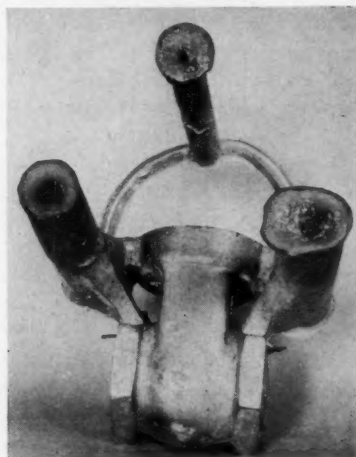


FIG. 5—QUICK OPENING 3 IN. GATE VALVE BODY—SHOWING IMPROVED METHOD OF GATING.

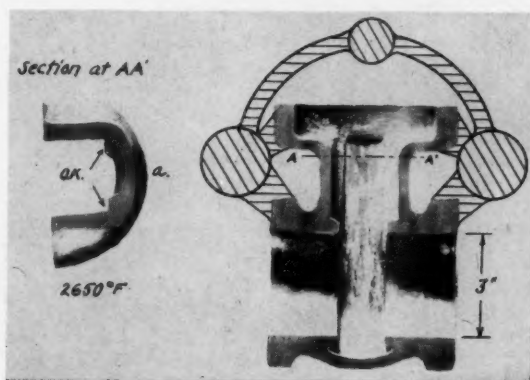


FIG. 6—QUICK OPENING 3 IN. GATE VALVE—SHOWING EFFECT OF MORE COMPLETE FEEDING.

37. The gating of Figs. 3 and 4 should give good results on castings poured between 2500 to 2600° F. However, the gating shown in Figs. 5 and 6 is less sensitive to high pouring temperatures and where feasible should be used. Its chief disadvantage lies in greater trimming costs.

38. Fig. 7 is a flanged gate valve, sections of which are shown in Fig. 8. Poured in a suitable temperature range this casting can be produced pressure tight quite readily. A range of 2500 to 2600° F. is satisfactory. Section *a* is from a casting poured at 2750° F., which leaked on hydraulic test, the photograph showing the reason; a pronounced shrink in the critical region. At 2635° F. the casting was pressure tight but showed a very small shrink in this portion. Section *b* shows the same area in a casting poured at 2585° F. and is quite satisfactory.

39. The sensitivity of this casting to incorrect pouring temperatures might also be diminished by a double gating of the type shown schematically in Fig. 5 for the quick opening gate valve.

40. Fig. 9 is a check valve poured too hot (2750° F.) and gated unsatisfactorily. The split section is shown in Fig. 10, with



FIG. 7—THREE IN. FLANGED GATE VALVE BODY.

the gating indicated. The difference in the amount of shrinkage between the better (section BB^1) and less adequately (section AA^1) fed portions of the casting is readily apparent and trouble might be expected at AA^1 even when poured at a suitable temperature. Fig. 11 shows a better method of gating, further illustrated in Fig. 12. Section a of Fig. 12 is cut from a casting made at

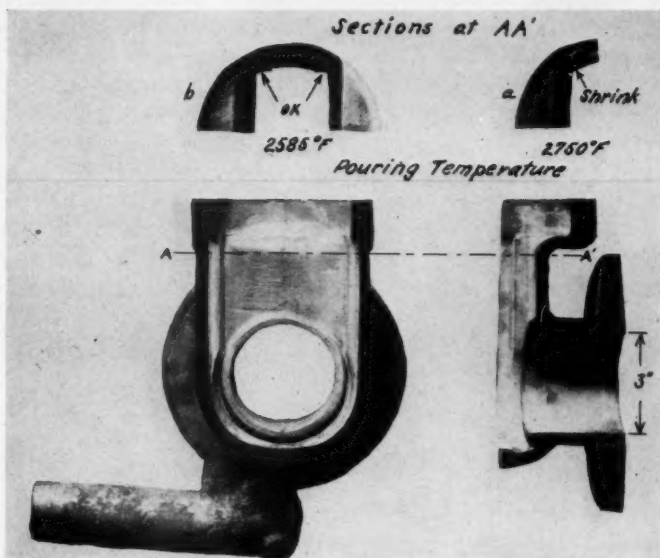


FIG. 8—THREE IN. FLANGED GATE VALVE BODY—SHOWING EFFECT OF POURING TEMPERATURE.



FIG. 9—FOUR IN. CHECK VALVE BODY, INADEQUATELY FED.

2575° F., which was pressure tight and quite satisfactory. A range of 2500 to 2600° F. should be satisfactory with this gating method.

41. Fig. 13 *A* and *B* are simple return bends cast at 2635° F gated quite generously in the case of casting *B*. Fig. 14 shows the same castings after sectioning. Casting *A* leaked at the shrink and casting *B*, with the more ample gate, was pressure tight and free from shrinkage. The return bend, gated as in *B*, has been cast pressure tight above 2700° F.

42. Fig. 15 shows a square flanged bushing with quite sharp

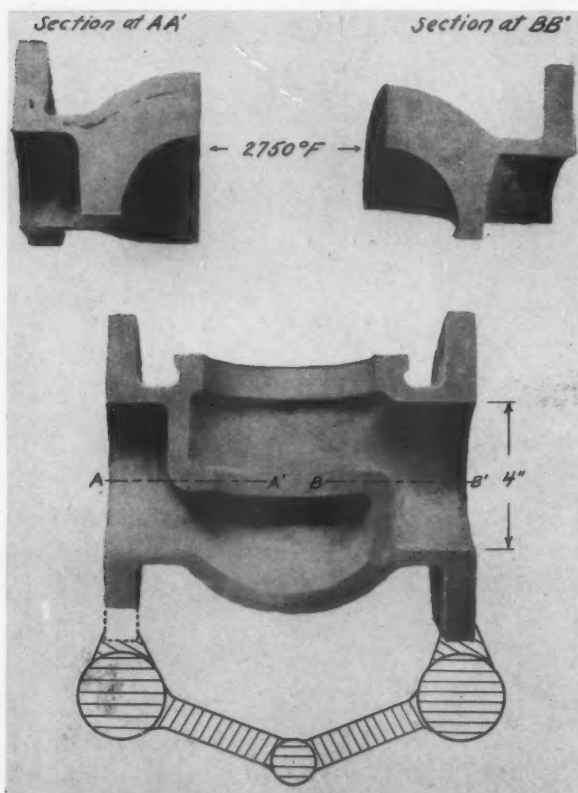


FIG. 10—FOUR IN. CHECK VALVE, CAST AT 2750° F.—POURED TOO HOT AND INCOMPLETELY FED.

corners and is included to illustrate the freedom from hot cracking of the mixture used.

43. It might be remarked that in addition to the feeding risers, which must be so gated that they will remain molten until the casting has been fed and is solidifying, very small risers may be usefully attached at appropriate points to provide a run off for any dirt which might be entrapped. The run-off risers should be so gated that they will freeze rapidly and not bleed the casting.

44. At the risk of being somewhat repetitious, these various examples illustrating the importance of exercising close control of pouring temperature and of molding procedure have been shown to emphasize their controlling influence on the quality of the castings. The gating methods indicated are not necessarily the best possible, but they do yield good castings under reasonably good temperature control.

45. Each foundry, of course, has its individual problems and these examples may at least be suggestive of other and perhaps better methods of feeding similar castings.

Pouring Temperature Control

46. *Measurement of Pit Temperature:* Generally speaking, it is helpful to obtain some estimate of the melt temperature be-

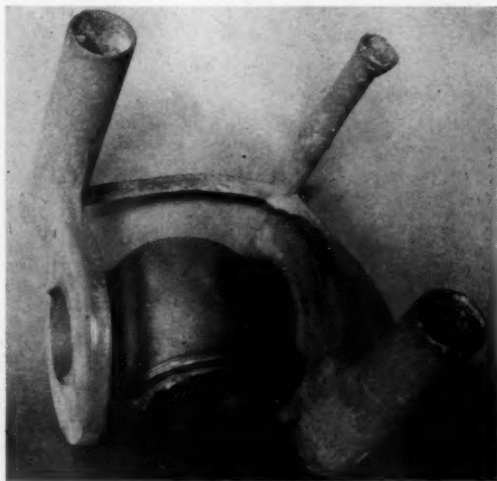


FIG. 11—FOUR IN. CHECK VALVE BODY—CORRECTLY GATED, FEEDING HEAVY SECTIONS.

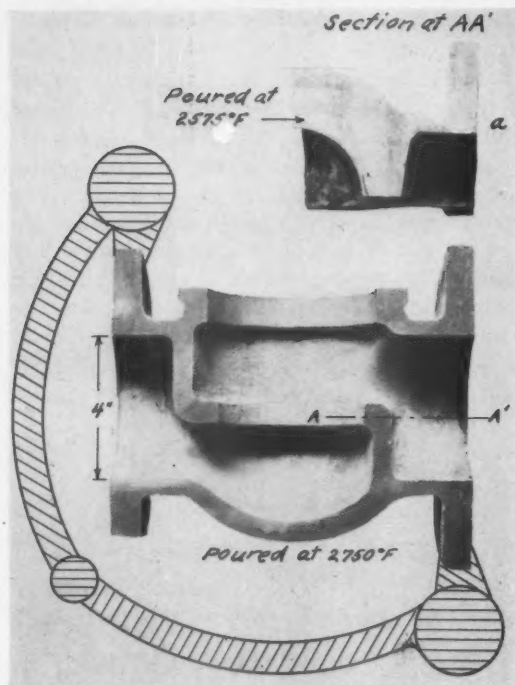


FIG. 12—FOUR IN. CHECK VALVE BODY—SATISFACTORILY GATED, PRESSURE TIGHT, CAST AT 2575° F.

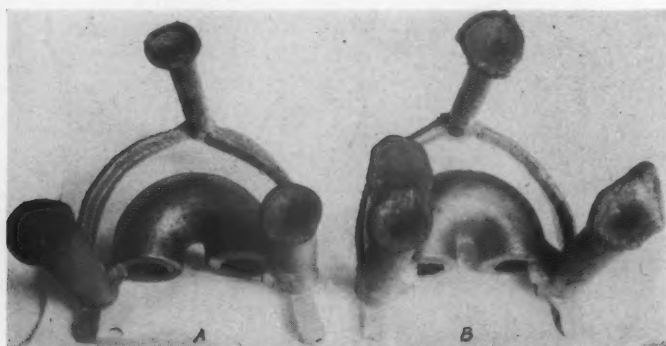


FIG. 13

A—RETURN BEND CAST WITH INADE-
QUATE GATES.

B—RETURN BEND AMPLY FED.

fore pulling the crucible (or tapping the heat) and a bare wire (14 gauge) chromel-nickel thermocouple of the extensible type used in conjunction with a portable type millivolt potentiometer can be employed with some success. While the measurement obtained is approximate, it indicates when the melt temperature is high enough to insure a sufficiently high initial casting temperature.

47. *Measurement of Casting Temperature:* For observed temperatures up to 2500 to 2550° F. an extensible bare wire 14 gauge chromel-alumel couple can be used in conjunction with a portable potentiometer if certain precautions are observed. The observed temperature, based on the millivolt temperature calibration chart supplied by the manufacturer of the wire represents the surface temperature and a correction of 75° F. must be added to the observed reading to obtain the melt temperature. A *fresh* junction should be used with each measurement. For obvious reasons the couple gives erratic results when used on melts having a glass cover. In the casting temperature range desired for 30 per cent cupro-nickel, the bare immersion couple which gives a reading in about 7 to 8 seconds, while supplying adequate control when properly used, nevertheless represents a compromise between speed and accuracy. A noble metal couple enclosed in an impermeable sheath which is enclosed in turn in a replaceable graphite sheath, and connected to a portable potentiometer read-



FIG. 14

A—INADEQUATELY FED RETURN BEND B—WELL FED RETURN BEND CAST AT 2635° F.



FIG. 15—CRACK TEST CASTING SHOWING FREEDOM FROM HOT CRACKING IN 30 Ni-1 Fe-1 Mn-0.5 Si ALLOY.

ing directly in ° F. is preferable for normal foundry control, inasmuch as some time is available for the initial reading. Once the desired initial temperature has been attained no further readings are essential.

48. For experimental work involving several temperature readings during the pour, the delay in obtaining temperatures is objectionable and for that reason the sheathed couple was not used in most of the present work.

49. The point which requires emphasis is the need for reasonably good control of pouring temperatures. As long as the method of measurement used yields sensibly reproducible values it matters little whether or not those values represent absolute or merely relative temperatures. Once the range of desired pouring temperature is established, as determined by that particular method, and adhered to, the desired control of this variable has been achieved.

PART 3—RELATIONSHIP OF CASTING COMPOSITION TO CASTABILITY AND PHYSICAL PROPERTIES

50. It has already been indicated that excellent castings can be made in 30 per cent cupro-nickel by the simple addition of 0.8 to one per cent manganese and 0.20 to 0.30 per cent silicon, and such castings should approach the wrought 70:30 in corrosion resistance. In actual practice, of course, small amounts of other elements will be frequently present. Such a mixture possesses adequate mechanical properties for cast fittings used in conjunction with 70:30 tubing. In other applications higher physical properties may be desirable or essential and this may necessitate increasing the silicon content and even introducing auxiliary strengthening elements.

51. Some information on the effect of such elements as zinc, tin, carbon, aluminum, iron, lead, and titanium, etc., whether inadvertently present as impurities, or deliberately added, on the castability and the physical properties seemed desirable, and some experimental melts were made for this purpose.

52. The experimental melts were for the most part 35 to 45 lb. melts made in a high frequency induction furnace using unlined clay graphite crucibles. The raw materials for the basic alloy were electro-nickel and fire refined electro-copper (99.9 per cent). The temperature readings were obtained with a bare chromel-alumel 14 gauge extensible thermocouple in the manner already described.

In some cases where heavy slagging occurred militating against a satisfactory reading, a protected noble metal couple was used.

53. The test casting consisted of a horizontally cast bushing 4 in. long x $2\frac{3}{4}$ in. O. D. x $\frac{3}{8}$ in. wall. Fig. 16 shows the gating used, which seemed to discriminate satisfactorily between various conditions of casting. A high permeability synthetic sand was used, faced with graphite, dusted on dry.

The Effect of Silicon

54. The addition of silicon *alone* (up to 0.62 per cent at least) to a simple 30 per cent cupro-nickel, without manganese or iron, has several undesirable effects. In the first place, the metal becomes quite sluggish to pour, a tough film or envelope forming about the stream of metal. Most of the hydraulic test bushings treated with silicon alone leaked at 40 lb. per sq. in. fluid pressure, with as little as 0.2 per cent silicon added. The fractures are very coarse as may be seen in Fig. 17 A and B. The occurrence of patches of smooth gray film suggest that the entrapping of the surface film previously referred to is an ever present hazard. As far as deoxidation is concerned silicon is very effective and castings so treated are entirely free from visible porosity. However, if we define soundness to imply freedom from both porosity and entrapped dross or dirt, it may be stated that silicon *alone* is entirely unsatisfactory. The pronounced coarsening effect of silicon

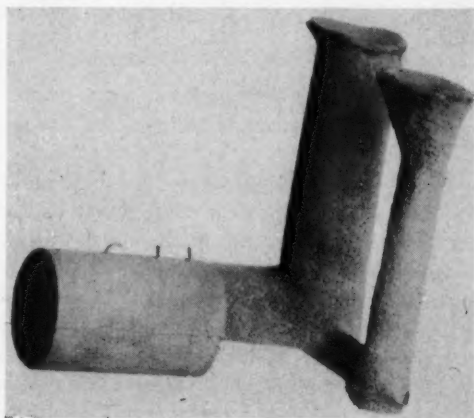


FIG. 16—HYDRAULIC AND FRACTURE TEST CASTING.

and the sluggishness in casting more than offset the toughness and freedom from gross porosity.

55. Inasmuch as several foundries were currently making 30 per cent cupro-nickel with fair success using 0.50 per cent and more of silicon, the above experiences seemed at variance with commercial practice. However, it was also realized that the commercial heats contained other elements besides silicon (such as iron and manganese) which might alter the situation markedly. Also earlier work on nickel silver suggested that either iron or manganese would oppose the grain coarsening tendencies of silicon.

Effect of Manganese Plus Silicon

56. Since it seemed quite probable that manganese would be more tolerable than iron as far as corrosion resistance was concerned, the former actually appearing somewhat beneficial in

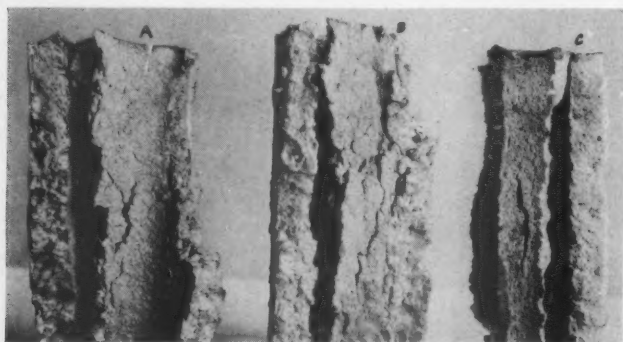


FIG. 17—COMPARISON OF FRACTURES OF CASTINGS TREATED WITH SILICON ALONE AND WITH SILICON PLUS MANGANESE

A—0.65% Silicon
0% Manganese

B—0.35% Silicon
0% Manganese

C—0.20% Silicon
0.80% Manganese

marine exposure tests of wrought alloys, it was thought preferable to study the effect of manganese in conjunction with silicon. The first experiments involved the use of manganese and silicon in a 4:1 ratio, borrowing from steel melting practice (Herty). Low carbon manganese metal and refined silicon were used for the additions, the two being added simultaneously to the melt.

57. The addition of 0.2 per cent Mn plus 0.05 per cent Si, the amount arbitrarily chosen for a "drawback" (i. e. the amount needed to combine with 0.10 per cent oxygen), imparted excellent fluidity to the melt but was inadequate to yield consistently satis-

factory castings, both sound and unsound casting being obtained with this treatment. It seemed probable that the margin of safety was too slim, variations in the degree of oxidation of the melt, prior to the deliberate oxidation treatment, influencing the amount of Mn-Si addition required.

58. Doubling the addition (0.4 per cent Mn plus 0.1 per cent Si) resulted in pressure tight castings with clean fine grained fractures. Of the heats so treated, the only bad casting was one made in a low permeability sand. Excellent castings were obtained with 0.6 per cent Mn plus 0.15 per cent Si; 0.8 per cent Mn plus 0.20 per cent Si; and one per cent Mn plus 0.25 per cent Si.

59. In all the melts treated with Mn plus Si in the 4:1 ratio excellent fluidity was obtained, in marked contrast to the manganese-free melts treated with as little as 0.20 per cent silicon. The latter, it will be recalled, were quite sluggish to pour, a thin but tough film forming around the stream. This film was entirely absent in the *manganese content* melts containing silicon up to 0.30 per cent, with manganese-silicon in the 4:1 ratio.

60. It may be concluded with reasonable certainty that the simultaneous presence of suitable amounts of manganese with silicon is accompanied by excellent fluidity, and the grain coarsening tendency of silicon *per se* is neutralized to a considerable extent. The former effect greatly diminishes the probability of the occurrence of dross inclusions in the casting, thus aiding in obtaining pressure tightness. The grain refining effect decreases hot cracking tendencies and also the probability of a continuous channel through which leakage from the inside to the exterior of the casting can take place. Manganese thus removes most of the disadvantages accompanying the addition of up to at least 0.30 per cent silicon, while maintaining and supplementing the effectiveness of silicon as a "deoxidizer."

61. Fig. 17 shows fractures of bushings in 30 per cent Ni-70 per cent Cu, treated with 0.8 per cent Mn plus 0.2 per cent Si (C), and with silicon alone in amounts of 0.35 per cent and 0.65 per cent (A) and (B). It will be noted that, while the fractures for the latter two have been damaged by the distortion in fracturing, the coarseness of structure is evident. However, the inside surface of the bushing where partial failure has occurred during fracturing is a better index and the cracking along the boundaries of the coarse crystals is quite apparent. In contrast, the Mn plus Si melt exhibits a quite fine fracture and the crack

on the inside surface indicates a relatively fine grain. (It should be remembered that this cracking occurred in all three bushings only after a great deal of hammering under the drop hammer in two directions at right angles; distortion of the fracture is therefore practically unavoidable.)

62. With additions of more than 0.25 per cent silicon, it is not necessary to maintain a 4:1 Mn:Si ratio, and up to at least one per cent of silicon may be added, in the presence of one per cent of manganese without adversely affecting the ease of pouring and with only a moderate grain coarsening tendency.

63. In the foundry, good castings may be made with the addition of one per cent of manganese plus 0.25 per cent of silicon. However, to provide a reasonable margin of safety and to obtain somewhat higher mechanical properties, a 0.50 per cent silicon level in the castings will be found preferable.

64. The lower set of curves of Fig. 18 show the effect of variations in silicon content, at a one per cent manganese level, on the tensile properties determined on bars cast in the pattern

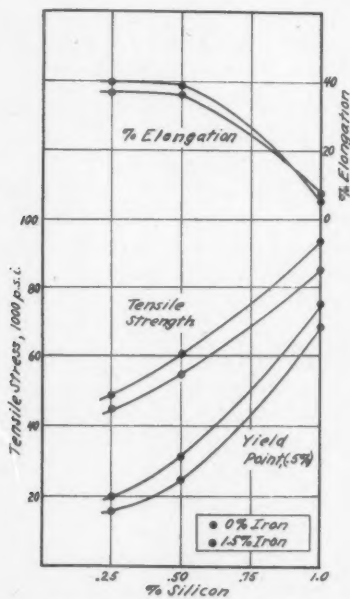


FIG. 18—EFFECT OF SILICON AND IRON ON 30% CUPRO-NICKEL (CONTAINING 1% MN).

shown in Fig. 1. It is apparent that silicon effects a marked influence on the physical properties of 30 per cent cupro-nickel. In the absence of iron, strengths ranging from 45,000 to 85,000 lb. per sq. in. and elongations from 35 to 10 per cent can be secured by suitable adjustment of the silicon content.

Effect of Iron

65. Iron in amounts up to 1.5 per cent has very little effect on the castability of manganese + silicon treated melts. In the absence of manganese, it tends to neutralize the undesirable effects due to silicon although it is less effective than manganese. As far as castability is concerned, iron is quite unnecessary in the manganese content mixture and its chief reason for inclusion would be its effect on the physical properties.

66. In the upper set of curves of Fig. 18 the effect of 1.5 per cent of iron on the physical properties of the variable silicon series (with one per cent manganese) is readily observed. In general, for a given silicon content, iron up to 1.5 per cent at least, increases the elastic properties rather sharply and the tensile strength moderately without loss of ductility.

67. Sea water tests on wrought 70:30 containing 5 per cent of iron developed severe pitting and rusting wherever the iron-rich excess phase had been precipitated. The maximum amount of iron which may be permissible from this angle is not known and it is suggested that it be kept below 1.25 per cent until further test data are available. The inclusion of iron in the casting alloy represents a compromise. In view of the heavier cross section of the castings compared to the wrought material with which it may be used, such a compromise is not unjustifiable and a one per cent iron level should not be objectionable. There are, of course, applications where iron can be advantageously added as an economical method of improving the properties. Alloys of the "Everbrite" type, containing about 30 per cent nickel and 6 to 8 per cent iron are examples of the latter, and one very successful application is shown in Fig. 19, involving the casting of "Everbrite" around the turbine blading to form the segments. Properties somewhat as follows are obtainable at the above mentioned nickel and iron levels:

- 75 to 85,000 lb. per sq. in. tensile strength
- 45 to 55,000 lb. per sq. in. yield point
- 15 to 20 per cent elongation in 2 in.

This class of alloys is strongly magnetic and due to the iron rich



FIG. 19—STEAM TURBINE REACTION BLADING—EVERBRITE BASE CAST AROUND BLADING (COURTESY ALLIS-CHALMERS MFG. CO.).

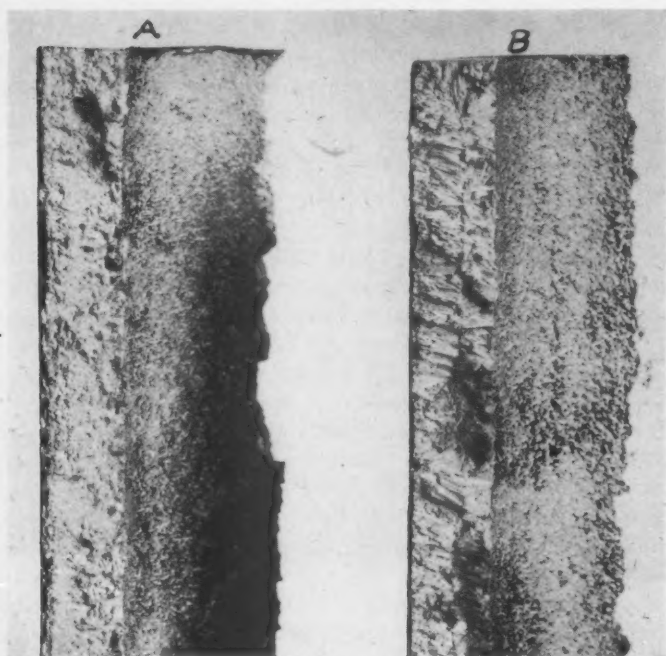


FIG. 20—EFFECT OF LEAD ON CUPRO-NICKEL CONTAINING 1% SILICON (ACTUAL SIZE).

A—0% Lead

B—0.25% Lead

0.1% Silicon
1.5% Iron
0.8% Manganese
26.0% Nickel
bal. Copper

phase precipitated does not provide suitable corrosion resistance to sea water.

Effect of Zinc

68. Zinc, used alone, up to 5 per cent is inadequate to deoxidize 30 per cent cupro-nickel, as might be expected, the castings being gassy. When added to an iron-free cupro-nickel properly treated with silicon + manganese, 1.5 per cent of zinc was found to have rather slight effect on either castability or physical properties. It may be useful as a scavenger but is far from necessary. At the temperatures involved, the zinc loss by volatilization is quite high and it is probable that the residual amounts in the casting will be rather small. Sea water corrosion tests in wrought alloys have indicated 5 per cent of zinc to be deleterious, causing pitting, and with this in mind a maximum of one per cent seems reasonable.

Lead

69. As might be expected, lead, even in small amounts, is extremely deleterious to silicon content alloys leading to leakers and excessively coarse structures and making the alloy hot short. Fig. 20 illustrates the effect of 0.25 per cent of lead. The lead content bushing shown on the right leaked on pressure tests and its extremely coarse fracture is readily observed. The physical properties obtained were as given in Table 2.

Table 2

	0% Lead 1% Silicon	0.25% Lead 1% Silicon
Tensile Strength (lb. per sq. in.).....	94,000	81,250
Yield Point (.5%) (lb. per sq. in.).....	77,650	78,850
Elongation in 2 in. (per cent).....	6	nil
BHN (1000 Kg).....	196	196

70. It is obvious that lead is a dangerous impurity in silicon content cupro nickels and virtually no tolerance for it should be permitted.

The Effect of Carbon

71. There are not many data on the effect of carbon. Such data as we have indicate that carbon exerts a mild strengthening effect, increasing the elastic and strength properties and very slightly diminishing the ductility. (This observation is based on a 0.14 per cent carbon melt containing 0.50 per cent silicon, one per cent manganese and 1.5 per cent iron.) Due to the limited

solubility of carbon in 30 per cent cupro-nickel, it is doubtful whether more than 0.20 per cent of this element would ever be encountered.

72. As far as castability is concerned, fracture tests on bushing castings suggest that low carbon melts give somewhat sounder, uniform castings. All the low carbon castings showed fine grained fractures and the 0.14 per cent carbon bushing fracture, while generally fine grained, showed a few isolated areas of very coarse crystals. Whether this indicates a segregation effect and whether or not it is characteristic of the higher carbon melts is not as yet known. The effect, however, has not been observed in low carbon melts.

Effect of Titanium

73. The addition of 0.25 per cent of titanium to a 30 per cent Ni-1 per cent Mn-0.50 per cent Si-bal Cu mixture, both with and without 1.5 per cent of iron was not found to have any beneficial effects but rather tended to make the fractures somewhat dirty. The iron-free bushing casting treated with titanium leaked on hydraulic tests and showed entrapped dirt, and also a suggestion of hot cracking tendencies. The tendency for dirty fractures was duplicated in the tensile specimen fractures.

74. The physical properties of the titanium treated melts were somewhat inferior to similar melts without titanium, especially with respect to ductility. Smaller amounts of titanium may be less objectionable and different melting conditions may also give a different response. It is also possible that titanium may have a different effect in the presence of carbon. However, under the conditions of melting used in this work, titanium was found quite unnecessary as far as the production of sound pressure tight castings was concerned, and, in fact, appeared to be deleterious. In passing it might be noted that titanium imparted a rather unpleasant brownish color to the casting skin, and this effect is somewhat undesirable.

Effect of Aluminum

75. Like silicon, aluminum added alone to a simple cupro-nickel, without manganese and silicon, imparts rather strong film forming tendencies to the melt, interfering with pouring. This effect was still pronounced in the normally very fluid 0.50 per cent silicon, one per cent manganese 30 per cent cupro-nickel. There

is always a strong possibility of entrapping some of the film as it breaks off and flows into the casting with the molten metal and from a castability angle, aluminum is preferably kept low.

76. Aluminum does increase the elastic strength properties quite sharply. It might be noted, however, that similar physical properties to a 0.50 per cent Si-one per cent Mn-one per cent Al cupro-nickel can be obtained in an aluminum free one per cent Si-one per cent Mn cupro-nickel and the latter alloy is much more fluid and casts more readily.

Effect of Tin

77. No test data are available on this element but it probably increases the physical properties and very likely improves the castability. Sea water corrosion tests indicate that the addition of 5 per cent of tin to wrought 70:30 causes moderate pitting, although it is far less objectionable than the same amount of either zinc or iron. Lower amounts of tin may be quite satisfactory in sea water and in other corrosion media may be helpful. A maximum of one per cent is suggested until sufficient data are available to set a justifiable maximum.

Suitable Casting Composition

78. Cupro-nickels which meet the following chemical composition should yield good pressure tight castings, possessing adequate corrosion resistance and mechanical properties sufficient to meet most of the requirements for which the alloy is suitable:

Per Cent		Per Cent	
Copper .....	.bal.	Lead .....	.05 max.
Nickel	28.5 to 31.5	Aluminum .....	.05 max.
Manganese .....	.060 to 1.20	Zinc	1.0 max.
Silicon .....	.025 to 0.75	Tin	1.01 max.
Iron	1.25 max.	Carbon .....	.015 max.
		Sulfur .....	.02 max.

79. Iron is limited to 1.25 per cent because of possible deleterious effects on corrosion resistance, especially in sea water and possibly should be kept below one per cent. The 0.75 per cent maximum on silicon is set to insure obtaining adequate ductility. The maximum aluminum content may be lower than strictly necessary, but in view of its bad film forming tendencies it is felt that appreciable quantities will cause trouble.

30 Per Cent Nickel-Silver

80. In view of the incompatibility of lead and silicon, it is

of course necessary to virtually exclude the former from the silicon content cupro nickels. However, the modification of 20 per cent cupro-nickel with tin and lead has been found in the past to improve its shrinkage characteristics and machinability, and make it easier to cast pressure tight.

81. In this connection, it might be noted that the *silicon-free* 30 per cent cupro-nickel modified with tin, zinc and lead, of Table 3, yielded a pressure tight bushing and a uniform clean gray fracture in the one melt* made. Such an alloy may be useful where a whiter color, with a higher degree of corrosion resistance is wanted than is offered by the Fed. Spec. 20 per cent nickel-silver casting alloy.

Table 3

Composition		Physical Properties	
	Per Cent		
Nickel	30	Tensile Strength (lb. per sq. in.)...	45,000
Tin	4	Yield Point (0.5%) (lb. per sq. in.)...	26,750
Lead	5	Elongation in 2 in. (per cent).....	12
Zinc	5		
Manganese	1		
Copper	Bal.		

* Treated with 0.05 per cent Mg + 0.02 per cent P shortly before pouring.

CONCLUSION

82. This paper is not intended to present a complete answer to the problem of producing cast 30 per cent cupro-nickel. It is hoped, however, that it will serve to clarify some of the factors involved therein and assist the foundryman in producing consistently sound and pressure tight castings.

ACKNOWLEDGMENTS

83. The author is pleased to acknowledge the stimulation and support of Mr. A. J. Wadhams and Dr. P. D. Merica, executive officers of The International Nickel Company, Inc. He also desires to express his thanks to Messrs. N. B. Pilling and E. M. Wise, Manager and Assistant Manager, respectively of The International Nickel Company, Inc., Research Laboratory, for their helpful suggestions and encouragement. A word of sincere appreciation is also due Mr. W. R. Hempstead, who assisted in carrying out much of the experimental foundry work connected with the preparation of this paper.

DISCUSSION

Presiding, HAROLD J. ROAST, Canadian Bronze Co., Ltd., Montreal.

JOSEPH A. DUMA¹: (Submitted as written discussion.) Mr. Kihlgren's paper on the "Production of Pressure Tight Castings in 30 Per Cent Cupro-Nickel" has been reviewed with interest. His experiences with that metal parallel very closely those of the writer in nearly all respects excepting one, namely—the effect titanium has upon the mechanical properties of that alloy. We have found that titanium is not only an excellent scavenging and deoxidizing agent, but a good auxiliary strengthening element. By combining with carbon, it prevents the formation of embrittling graphitic carbon, thus insuring freedom from micro-cavities which, in turn, means greater resistance to hydraulic pressure. Titanium carbide, more than graphitic carbon, improves the machinability of this alloy; it is also more resistant to salt spray corrosion than uncombined carbon.

Our practice of incorporating titanium into the metal is somewhat different from the one described by Mr. Kihlgren, it being:

(a) *Electric Furnace Practice:* Electrolytic copper, electrolytic nickel, and a small quantity of charcoal are charged and melted down under an alumina-aluminum slag in a half ton electric (arc) furnace. When the charge is melted, small quantities of ferromanganese, ferrosilicon, and iron are added. The heat is then finished with a titanium oxide-aluminum (two parts TiO_2 and one part aluminum) addition. After the reaction between the oxide of titanium and aluminum is completed, the metal is poured into small ingots. The metal from the electric furnace possesses good physical properties and there is no disadvantage from pouring castings directly from the electric furnace (ladle) if there is sufficient tonnage to justify this practice. Of course, heats which are intended for direct pouring of castings are made with the full addition of required elements; to those intended for ingots, approximately half as much silicon and manganese are added.

(b) *Crucible Practice:* Electric furnace ingots together with a small quantity of lead-free glass are charged into a preheated clay-lined or Tercod crucible, the crucible covered, and the charge melted down as rapidly as possible in an oil-fired pit furnace. After the charge is entirely melted, the cover is removed and the desired quantities of silicon, manganese, and other additions are made at this time. The crucible is then heated for a period of five to ten minutes, removed from the furnace, and two ounces of phosphor-copper per hundred pounds of charge stirred into the metal immediately before pouring. Titanium is not added to the crucible.

Taking a specific example, an electric furnace heat made as described above, and analyzing as follows gave the properties as listed.

C	Mn	Si	Fe	Ni	Cu	Ti	Al
0.08	0.60	0.22	0.75	28.00	70.46	0.11	0.14

Tensile Strength		Yield Point (Divider Method)	Elongation
Lbs. per Sq. In.		Lbs. per Sq. In.	
61,250		25,500	39.5% in 2 in.

¹ Junior Metallurgist, Norfolk Navy Yard, Portsmouth, Va.

When remelted in the crucible under the conditions described above and poured at approximately the same temperature, the resulting alloy analyzed thusly:

C	Mn	Si	Fe	Ni	Cu	Ti	Al
0.12	1.00	0.57	0.88	27.81	69.47	0.05	0.08

A fin gate test bar (Composition G Type bar as per drawing in N. D. specification 46M6e) of this analysis pulled:

Tensile Strength	Yield Point*	Elongation
78,750	50,000	31.0% in 2 in.

In paragraph 78 there is given a suitable casting composition for 70-30 cupro-nickel. It is surprising that the author did not include a similar suitable bogey of minimum physical properties to accompany the recommended mixture. A study of our data compiled from the manufacture of some 40 different crucible and electric furnace heats shows that properly made sandcast 30 per cent cupro-nickel of an analysis such as shown in the table of paragraph 78, should give properties in excess of the following minimum values:

Tensile Strength	Yield Point*	Elongation
Lbs. per Sq. In.	Lbs. per Sq. In.	20% in 2 in.
65,000	32,000	

MR. KIHLOREN: I wish to thank Mr. Duma for his interesting comments detailing his experience with 30 per cent cupro-nickel castings. Mr. Duma takes exception to our statement regarding the effect of titanium. However, in paragraph 74 we stated that the effect of titanium might be quite different under other melting conditions and/or in the presence of carbon, and it is significant that the conditions of melting used by Mr. Duma produce metal containing generally 0.10 per cent or more of carbon.

The examples cited by Mr. Duma do not demonstrate the efficacy of titanium, but rather show that the silicon content is the controlling factor as far as strength properties are concerned, the increase in silicon from 0.22 to 0.57 per cent being largely responsible for the increase in strength, with the rise in iron, carbon and manganese content exerting auxiliary strengthening effects.

Mr. Duma refers to the section on "suitable casting composition" (paragraph 78) and indicates that data compiled from 40 different electric and crucible furnace heats suggest that properly made 30 per cent cupro-nickel of the analysis indicated therein should give properties in excess of 65,000 lb. per sq. in. tensile strength, 32,000 lb. per sq. in. yield point (divider method) and 20 per cent elongation. I should like to point out that the analysis referred to covers a considerable range of composition and consequently of physical properties. I do not believe that a simple 30 per cent cupro-nickel containing 0.25 per cent silicon and one per cent manganese, and essentially free of iron, carbon, aluminum, phosphorus, tin, etc. is inherently able to develop over 55,000 lb. per sq. in. tensile strength, and 20,000 lb. per sq. in. yield point (using strain gage, not dividers) although the elongation will be more than double the minimum

* Divider Method.

suggested by Mr. Duma. I quite agree that many alloys falling within the compositional range indicated will exceed the minima suggested. For example, at the highest silicon level indicated in paragraph 78, a 30 per cent Ni, 0.75 per cent Si, 1.25 per cent Fe, 1 per cent Mn alloy containing small amounts of carbon, aluminum, phosphorus, etc. would develop properties in excess of 75,000 lb. per sq. in. tensile strength, and 50,000 lb. per sq. in. yield point and still retain about 20 per cent elongation.

It should be pointed out that most of the heats on which Mr. Duma bases his minimum tensile properties contain, in addition to copper, nickel, silicon and manganese, small amounts of carbon, aluminum, titanium, etc., and appreciable amounts of iron. The data cannot, therefore, be used to indicate the physical properties to be expected on a simple 30 per cent cupro-nickel containing 0.25 per cent Si, and one per cent manganese, and essentially free of iron and other elements.

Unquestionably the practice used by Mr. Duma produces excellent quality metal developing very good physical properties, and we are indebted to him for his description of the melting procedure used. As he states, his experiences parallel those of the writer very closely, and even the exception which he takes (i.e. on the effect of titanium) is not contradictory, when one considers the different conditions of melting and casting composition involved.

W. M. BALL, JR.²: I would like to ask whether the author has done any work on this particular alloy with regard to its physical properties at elevated temperatures, such as 500°F.? I believe if this alloy is to succeed, it will be necessary for us to give to the engineering profession the necessary information relative to the creep test and physical properties at elevated temperatures, because one of the main applications of this alloy is that it will be running under elevated temperatures between 300 to 500°F., and we have found on other bronze alloys that when we made our physical test at elevated temperatures there was quite a reduction in physical properties of the alloy.

MR. KIHLGREN: We have not made tests at elevated temperatures. Since we were trying simply to develop a suitable procedure for the production of sound castings, all the tensile tests in connection with this paper were made at room temperature.

J. J. KANTER²: In regard to the question raised about the mechanical characteristics of 30 per cent cupro-nickel at elevated temperatures, attention might be called to some experiences with solder fittings cast from the alloy. In a number of instances it was found that such fittings cracked upon installation. Aligning of fittings, at the stage of cooling while the high temperature solder used is still plastic, presumably introduces strains upon the fittings responsible for the cracking. A temperature in excess of 1200° F. is used to make the solder flow, thus the failures can occur while the fitting metal is under dull red heat. The failures suggest that the ductility of the alloy while hot is insufficient for such installation abuse.

Studies upon the hot ductility of the alloy were made by heating a

² Foundry Supt., Edna Brass Mfg. Co., Cincinnati, O.

² Research Metallurgist, Crane Co., Chicago.

number of solder fittings to 1200°F. and flattening by hammer until cracking could be observed. These fittings represented various heats so chosen that ranges of composition with respect to addition elements such as silicon, tin, manganese, and carbon, could be studied for their effects upon hot ductility. The fracture of 30 per cent cupro-nickel at temperatures of 600°F. or greater has a dendritic contour in contrast to the silky one when fractured cold. The dendritic fracture seems to be associated with the hot shortness of the alloy, and additions of silicon and tin seem to accentuate a sensitivity to such breaks while hot.

The liberal addition of silicon or tin for bolstering the strength of this alloy at ordinary temperatures for the purposes of meeting set specification requirements seem of dubious merit in view of the fragility at a temperature above 600°F. when this is done. High temperature toughness and ductility is much more of a strength factor than high yield points at 70°F. Specifications for fittings of 30 per cent cupro-nickel to be exposed to high temperature either in course of installation or service should give due regard to these considerations, requiring only the composition and physicals permitting satisfactory hot ductility.

GEO. P. HALLIWELL¹: In paragraph 5 of the paper, it is stated "that there is no sharp line of demarcation between the cupro-nickels and nickel-silvers." At the Non-Ferrous Round Table Meeting yesterday, there was considerable discussion on nickel-silvers. In considering the composition suitable for one of the castings under discussion, it was stated that 4 per cent lead in a 20 per cent nickel-silver could be used. Now, I would like to know wherein is the line of demarcation for the addition of lead between cupro-nickels and nickel-silvers.

MR. KIHLGREN: When I said there was no sharp line of demarcation, I meant chiefly this: That after all nickel-silver is nothing more or less than a copper-nickel to which tin, zinc and lead have been added. I might also say that the nickel-silver customarily used for pressure work is nothing more nor less than red brass to which nickel has been added. There is not a sharp line of demarcation.

When you speak of the nickel-silvers used in pressure fittings, it is quite true you have considerable tolerance for lead. As a matter of fact, lead is one of the very useful elements present, and up to 10 per cent is helpful as far as castability is concerned. In the presence of lead, however, there are decided limitations on silicon. If you consider the nickel-silvers as copper-nickels with lead, tin and zinc in them, silicon should be virtually absent if pressure tight castings are to be obtained.

On the other hand, considering the cupro-nickels, these will normally contain up to 0.75 per cent silicon and the tolerance to lead is very low in the presence of the silicon. In other words, the thing we want to bring out is this: In lead content nickel-silvers, silicon is a dangerous impurity, and in silicon content cupro-nickels, lead is decidedly detrimental, even in very small amounts.

MR. HALLIWELL: It was also stated in the round table discussion that carbon was not to be tolerated in nickel-silvers, yet a maximum of 0.15

¹ Metallurgist, H. Kramer & Company, Chicago, Ill.

per cent is placed for cupro-nickels in the present paper. Could you give us any information which would reconcile these apparently opposite opinions.

MR. KIHLGREN: The effect of carbon is not too well known. Of course, we all know the solubility of carbon in a 20 or 30 per cent cupro-nickel is very low, and in wrought alloys, carbon does lead to some difficulties. However, in a casting, I would not expect that a carbon content of say 0.10 per cent would be very objectionable.

E. F. HESS⁵: What effect is produced on the hardness by increasing amounts of silicon, also was the metal poured into molds made of different sand? If so, was any effect upon the cleanliness of the castings noticed?

MR. KIHLGREN: As far as the first question is concerned, of course, the hardness does increase along with the tensile strength. At the one-quarter per cent silicon level (without iron), the hardness, if I recall correctly, is about 90. It goes up to about 190 at one per cent silicon.

As far as sand is concerned, we have not done very much on that. During the experimental work which we were carrying on, we had normally been specifying synthetic sand of rather high permeability. We were doing that purposely because we wanted to make sure that any difficulties we ran into could not be ascribed to the sand.

As to the castings which I showed in the slides, those were all made with synthetic sand of around 90 permeability and faced by graphite dusted on dry; the surfaces were generally fairly satisfactory. I think it is important to remember that at the high casting temperatures used for cupro-nickel, it is essential to use a good refractory sand of fairly high permeability (60).

MEMBER: What have you found as to the use of chills?

MR. KIHLGREN: Nothing has been done on that. All these castings are of a type such that we did not find it necessary to use a chill. I think though it would be true, as it is in many of the other alloys having relatively small freezing ranges that where you have heavy sections in a casting at some point where you cannot conveniently feed it, a chill will be very useful to equalize the freezing rates of the heavy and light sections.

MEMBER: I would like to ask Mr. Kihlgren to repeat those statements about the effect of silicon and manganese on the fluidity of the mixture and the melting, and also if sulphur would have any effect.

MR. KIHLGREN: The point I mentioned as far as the effect of silicon and manganese on fluidity is concerned, is simply this: If we add silicon alone to a simple cupro-nickel, the melt is quite sluggish to pour, but if we have manganese (about one per cent) as well as silicon present, the melt is very fluid and pours easily. As far as the sulphur is concerned, we view it with suspicion, because of its detrimental effect on hot and cold ductility of nickel alloys. We, therefore, suggest that a small amount of magnesium (.025 per cent) be added to take care of any sulphur that might be picked up during melting and that low sulphur-content fuel oil or coke be used.

⁵ Metallurgical Engineer, Ohio Injector Co., Wadsworth, O.

MEMBER: Could sulphur be picked up through your furnace if you were using a coke fire?

MR. KIHLGREN: Quite probably.

MEMBER: What do you use, oil fired or gas fired?

MR. KIHLGREN: We use oil fired crucible furnaces and a fuel oil that has a maximum sulphur content of 0.60 per cent. I think generally it runs somewhat below that.

J. J. CURRAN^a: Wrought cupro-nickels containing about 30 per cent nickel, and essentially free from tin, lead, and zinc have become popular for corrosion-resistant service, particularly in contact with sea water and brackish waters. The cast alloy is also used rather extensively for valve trim and fittings where resistance to corrosion, strength, and hardness are desired.

The successful casting of the alloy requires considerable care, but with experience and proper attention to melting and foundry practice, excellent results are obtainable. Mr. Kihlgren's paper emphasizes well the necessity for proper gating and feeding, and proposes a method of melting and deoxidation which has possibilities.

His method of oxidizing the metal and then reducing in the last stages of the heat is a practice which might well be applied to general foundry practice in many other alloys. By keeping the metal oxidized until hot enough, to pour, and then deoxidizing, difficulties with reducing gases may be minimized.

One difficulty which has been noticed in this type of alloy with iron, manganese, and silicon, is the extreme variation often encountered in physical properties. Two heats of almost identical composition may be far apart in strength and ductility.

One rather widely circulated purchase specification covering this alloy requires minimum values for yield point of 32,000 lb. per sq. in., for tensile strength of 50,000 lb. per sq. in. and for elongation of 20 per cent. This calls for an elastic ratio of about 64 per cent, which is not commercially attainable with the elongation required. The writer has observed that when this ductility and strength is desired, an elastic ratio of not over 45 per cent should be specified.

Sulphur within reasonable limits does not seem to affect the alloy, but continual pick-up in remelting makes it desirable to avoid it as much as possible.

Lead and silicon occurring simultaneously are incompatible in copper alloys, but our own experience leads us to believe that in the presence of 30 per cent nickel they do not react to give the unsoundness which they produce in red brass. At least, there is enough evidence in this direction to make it unsafe to say that they are absolutely incompatible, in the cupro-nickels.

MR. KIHLGREN: Mr. Curran mentioned encountering wide variations in physical properties of 30 per cent cupro-nickel (containing iron, manganese and silicon), two heats of almost identical composition being often far apart in strength and ductility. It is not improbable that, were Mr. Curran to analyze two such heats of nearly identical silicon, iron and

^a Research Metallurgist, Walworth Co., Greensburg, Pa.

manganese contents for such elements as lead and sulphur, he might find the reason for such variations. As little as 0.25 per cent of lead may lower the ductility to a negligible value and rather small quantities of sulphur may be expected to reduce both hot and cold ductility unless a sufficiently high manganese content is employed, or a small amount of magnesium added before casting.

MR. CURRAN: Mr. Kihlgren, on the point of sulphur, it seems to me I heard you say there was 0.14 per cent sulphur in that alloy. Am I correct?

MR. KIHLGREN: No, that is incorrect. I believe you may be referring to a statement originally made in discussion of Mr. Keeley's paper on nickel silver at the Toronto A.F.A. meeting in 1935. At that time I mentioned that we had deliberately added 0.05 per cent of sulphur to a 20 per cent nickel silver containing 6 per cent of zinc (deoxidized with 0.05 per cent magnesium) and obtained a quite satisfactory casting. However, in 30 per cent cupro nickels containing little or no zinc, the tolerance for sulphur is probably quite low. In any event, all possible precautions should be taken to prevent sulphur contamination by careful control of foundry procedure. At best, the variables in the production of castings are many, and the more they are eliminated or controlled, by that much the job of getting good castings has been simplified.

MR. CURRAN: The point is, we have heard all this stuff about oxidation and sulphur pickup, and the fact is that these metals should be melted under oxidizing conditions to prevent gas pickup. A little sulphur, more or less, is not going to hurt you because you put it in and found it perfectly all right.

MR. KIHLGREN: It depends upon what alloy you are talking about. As I mentioned, we found that the addition of 0.05 per cent sulphur in one instance did no *visible* damage to a *zinc content* 20 per cent nickel-silver containing magnesium but I would hardly call it good practice. That amount of sulphur would be very much open to suspicion in a zinc free 30 per cent cupro-nickel.

MR. CURRAN: On the subject of lead, we feel that in an alloy without nickel, silicon is, of course, very detrimental in the presence of lead. In the case of the nickel alloys, as far as I have found, the silicon is so bound up with the nickel that it does not produce the bad effect with lead that you will get in the cupro-nickel. At the same time, I do not believe we should have lead unnecessarily in an alloy of this sort, 30 per cent cupro-nickel.

There is one other point. The Navy specifications for this call for 32,000 yield point, and about two years ago I criticized it. I said, I would try real hard to give 25,000, but they still stick to the 32,000. I have seen something on this from you in the mean time. I would like to get into the records that you do not believe that 32,000 is a proper yield point for this 30 per cent cupro-nickel with 50,000 tensile.

MR. KIHLGREN: There are a couple of things I would like to say in this connection. In Mr. Curran's earlier remarks he indicated that when nickel was present, lead was not quite so objectionable. I might mention

briefly that we found some rather interesting things on the effect of lead on cupro-nickels containing silicon at higher nickel levels. As a matter of fact, one company that is producing high nickel castings had considerable trouble with cracking of the castings. It was found that the castings contained 0.1 per cent lead. That seemed a rather small amount. Nevertheless, castings were made in the laboratory in which 0.10 per cent of lead was found to coarsen the grain and produce "leakers." The foundry in question then set aside one furnace solely for making the cupro-nickel heats to avoid lead contamination and have since encountered no recurrence of cracking.

I am, therefore, skeptical about the advisability of permitting virtually any lead in the cupro-nickels containing appreciable amounts of silicon.

The other point Mr. Curran brought up is well taken. There is a minimum yield point of 32,000 pounds now specified. Now, with one-half per cent silicon and one per cent of iron, you can just about get that in 30 per cent cupro-nickel. If you have in addition small amounts of aluminum, carbon and a few other elements, you will exceed it fairly comfortably. But I rather question the necessity of having high strength material for the purposes for which castings in this alloy will be employed in connection with its use along with wrought 70-30 tubing. Actually, as Mr. Curran mentioned, unless you have other elements in the mixture besides manganese and silicon, or step the silicon up to 0.60 or 0.70 per cent, you will have trouble meeting the minimum specification of 32,000 yield point.

T. E. KIHLOGREN (*Author's written closure*): We should like to take this opportunity to thank those who have taken part in the discussion of this paper. There is much work that should be done to increase our knowledge of the physical and casting characteristics of this group of casting alloys, including the effect of such impurities as carbon, sulphur, lead, etc. It is hoped that the present paper will be helpful in shaping further casting studies.

We should also like to acknowledge Mr. Kanter's helpful discussion. The point of view he expresses—that "the bolstering of the strength of the alloy at room temperature by the liberal addition of silicon is of dubious merit, etc." is one in which we concur and we should prefer to see the silicon at 0.40 to 0.50 per cent for general applicability.

Recent tests at the laboratory, made since the paper was presented, have shown that 30 per cent cupro-nickel containing 0.75 per cent silicon and 1.5 per cent iron exhibits rather severe hot cracking tendencies when subjected to stresses during solidification, *in the absence of manganese*. This cracking is largely eliminated by the presence of 1.0 to 1.15 per cent residual manganese (1.20 per cent added), a point which may be of considerable interest.

However, for most purposes to which the castings are to be put, 30 per cent cupro-nickel containing 0.25 to 0.50 per cent silicon should possess adequate physical properties. It will probably be less fragile at elevated temperatures and as a consequence less susceptible to hot cracking if subjected to thermal stresses during cooling from the casting temperature.

Insulating Refractories

Their Manufacture and Physical Properties

By G. A. BOLE¹, COLUMBUS, O.

Abstract

An insulating refractory is defined as "a product with low heat conductivity suitable for use as a lining for furnaces." As the use of this product has developed with astounding speed, insulating materials and methods of manufacture have not been standardized. This paper is largely confined to a review of methods of manufacture, properties, testing, specifications and applications. Celularity is said to be obtained in a number of ways. These methods are discussed together with difficulties encountered in manufacture. The use of large shapes is advocated. Under tests and specifications the author takes up classification, size, suitability, load, reheat, shrinkage, heat flow, conductivity, porosity, spalling and strength. Properties of various samples are tabulated. Advantages of use are discussed under thermal conductivity and furnace construction. The author concludes his discussion with a word of caution as to certain factors which must be considered.

1. The use of insulating fire brick has moved in on us with astounding speed. The use of the product and the methods of manufacture have not yet been standardized. The very large savings reported in fuel consumption and in the time of heating up a furnace are reasons enough for the average furnace builder and operator to question very seriously whether or not his furnace should be built of this new type of refractory. Each new issue of catalogs records a new use for insulating fire brick.

2. The American Society for Testing Materials defines² an insulating fire brick as follows: "A product with low heat conductivity suitable for use as a lining for furnaces."

3. May we not, for the remainder of this paper, review the methods of manufacture, the properties, the methods of test and the specifications for this new type of refractory?

¹ Research Professor of Ceramic Engineering, Ohio State University.

² American Society for Testing Materials, Tentative Specification C71-36T, Definitions Relating to Refractories.

NOTE: Presented before Refractories Session of the 41st Annual Convention of the A.F.A., Milwaukee, Wis., May 6, 1937.

PROBLEMS INVOLVED IN MANUFACTURE

4. Cellularity is obtained in a number of ways³: (1) the burning out of added combustible, (2) the addition of cellular minerals such as infusorial earth, (3) chemical cellulation, (4) sublimation of an organic compound, (5) the addition of expanded minerals such as kyanite and vermiculite, and (6) the development of a stabilized foam in the clay slurry.

5. All but the last named method have been used commercially in the United States for the production of refractory insulation or insulating fire brick.

Burning Out of Added Combustible

6. By far the greater number of brick are made by the first named process—the burning out of added combustible. The method of manufacture under this process varies from a soft mud, through a stiff mud, to a semi-dry press process. There are advantages claimed for each of these methods of manufacture. There are now twelve companies making an insulating fire brick with more to follow.

7. The combustible employed is usually some form of wood fiber. Cork granules are claimed by one company to give a superior and dependable type of cellularity. In the case of one high grade brand the wood flour is said to be ground to an extremely fine degree of subdivision. An aeration process completes the essentials of manufacture of this product.

8. One company uses a combination of the burning out and the sublimation processes to advantage. Another company claims advantages for chemical bloating by the interaction of a carbonate and an acid.

Chemical Bloating and Frothing Methods

9. The chemical bloating and the frothing method are quite simple in their operation and give an exceptionally uniform product, from which no combustible need be burned out. The last named method is a laboratory suggestion, but may at any time become a commercial method. Instead of starting with a mud as do the other methods, these methods start with a thick clay slip. The difficulty so far has been in securing a proper stabilizing or setting up agent. When the slip is cellulated, it will slowly slump when dried if not properly stabilized. This stabilization of the

³ *Development of Light-Weight Clay Products*, G. A. Bole, Engineering Experiment Station Ohio State University Bulletin 84, 1934.

cellulated mass has been attempted by the addition of plaster of Paris, refractory cements, and the development of a gel in the clay mass. A beautiful laboratory product has been obtained, but it has not been found feasible to commercialize the manufacture as yet. The addition of plaster of Paris is, of course, objectionable in that it lowers the refractoriness of the finished product. A hydrous silicic acid gel and a hydrous aluminous oxide gel have been used successfully in the laboratory to set up the cellulated clay mass but have not been commercialized.

10. The patent literature is full of proposed cellulation methods. One interesting procedure is the addition of powdered aluminum and an alkali to liberate hydrogen gas which acts as the cellulating agent. The expansion of kyanite, vermiculite, or a similar mineral, presents the problem of a proper bond. The expanded minerals themselves are weak in structure.

11. Much can be said in favor of the various methods outlined. Each, unfortunately, presents certain fabrication difficulties which may or may not be overcome through additional research.

Difficulties in Manufacture

12. The method of fabrication by burning out a combustible introduces problems which involve manufacturing difficulties. It is quite difficult, although not impossible, to avoid internal laminations along structure planes. There are difficulties in drying which have to do principally with the sizing of the wood product and the particular type of wood used. Hard wood is said to be the ideal material, but is expensive and difficult to secure. The users of cork claim that a good many of these difficulties are eliminated when cork dust is used instead of wood fiber.

13. The firing of a kilnful of the product is, indeed, a tricky problem, but one which the fabricators have fairly well under control. Because of their mechanical weakness during certain stages of the burn, it is impossible to stack cellulated refractories more than a few courses high. The firing costs have, accordingly, been excessive. Such costs have been minimized in some cases by firing only a few courses of insulating fire brick on top of the dense refractory setting.

14. Practically all insulating refractories are sized on cutting tables after they have been fired. This gives a product that is accurately shaped, but, of course, adds considerably to the cost of fabrication. When one considers all the difficulties involved in the

fabrication of the product, one is not surprised that the selling price of insulating refractories is considerably higher than that of the dense brick.

Advantages of Using Larger Shapes

15. Since a very large part of the difficulty involved in laying brick into furnace walls has to do with the joints and jointing material, it would seem logical to use a larger shape, thus reducing the number of joints. This would be possible with some of these refractories as they are first made into large dobies and then cut to the nine-inch standard size. The possible objection to making blocks is that large shapes might have a poorer spalling resisting tendency. Some manufacturers are reducing joint difficulty by offering their product in a double brick size.

TESTS AND SPECIFICATIONS FOR INSULATING FIRE BRICK

Classifications

16. It is interesting to note that several classifications will have to be made in the case of cellulated refractories. The brick are beginning to divide themselves along two lines: (1) a material that will serve as a back-up for dense refractory walls, and (2) a material that can give service under direct flame impingement with or without a thin coating of a refractory cement. This latter group divides itself into low temperature, intermediate temperature, and high temperature insulating fire brick. The temperatures tentatively agreed upon for these three divisions of service limits are 2200°, 2500°, and 2800° F. These divisions, I might say, are entirely arbitrary and will probably be altered when specifications are finally written.

Size Specification

17. Size specifications offer no difficulty as the brick are trimmed to shape after they are fired. The brick have a special advantage in construction over dense refractories in that they can be cut to shape on the job with a steel saw.

Suitability Specifications

18. Test specifications for suitability under various service conditions are a problem which is causing the American Society for Testing Materials considerable worry at the present time. The ultimate P.C.E. of the materials used has very little to do with the service of the product. The size of the pores, the pore contour,

and more particularly, the structure of the cell walls define the temperature at which an insulating brick may be used.

Load Tests

19. The steep temperature gradient encountered in the furnace wall makes it quite apparent that the standard American Society for Testing Materials⁴ load test has little value except in special cases. A load test involving heating the brick on one side only and subjecting it to load under these conditions has been

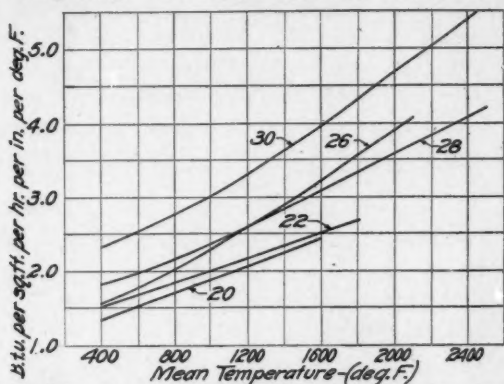


FIG. 1—CURVE SHOWING THE CONDUCTIVITY OF ONE COMPANY'S INSULATING REFRACTORIES.

suggested by Stuart M. Phelps⁵ of Mellon Institute. Mr. Phelps appears to think that if a load test is to be specified at all this method of test has merit. Sufficient data are not available upon which to write a specification. It has been suggested further that the brick should be tested under a load proportional to their weight; in other words, a brick weighing less than one-fourth as much as ordinary fire brick should be tested under a load of six pounds instead of the customary twenty-five pounds per square inch.

Reheat Test

20. The specification that has given the clearest distinction between various grades of insulating refractories involves data obtained in the reheat test⁶. Whether this will finally go through in the same form as for dense refractories or whether it will be a test involving the heating of one face only is problematical. As

⁴ A.S.T.M. C 16-36.

⁵ *Properties of Insulating Refractories*, S. M. Phelps, American Refractories Institute Bulletin No. 61.

⁶ A.S.T.M. C 113-36.

at present used, it involves the heating of a standard brick laid edgewise, carried to the temperature involved and held at that

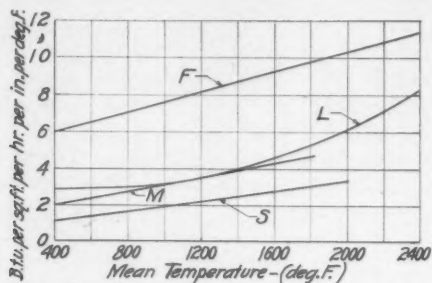


FIG. 2—A CURVE SHOWING THE EFFECT OF PORE SIZE ON CONDUCTIVITY.

F=Dense Fire Brick
 L=Large Pores (Insulating Fire Brick)
 M=Medium Pores (Insulating Fire Brick)
 S=Small Pores (Insulating Fire Brick)

temperature for a specified time. The panel test involves a soaking heat for 24 hours. The furnace used for the test is essentially similar to the preheat furnace in the spall test. The furnace atmosphere has been found to have a profound effect on the shrinkage of these brick. No specification for allowable shrinkage has yet been suggested.



FIG. 3—THE FURNACE USED IN THE PANEL SHRINKAGE TEST (COURTESY OF MELLON INSTITUTE).

Shrinkage

21. A quite wide variation in the shrinkage of refractories sold for service at a given temperature is encountered. The refractories are, however, beginning to find their own service level, and it will only be a matter of time until all cellulated refractories will be sold for the particular shrinkage service involved.

Heat Flow

22. It is essential that an insulating brick be true to its name. The property of heat flow is possibly the most difficult of all values to estimate. There have been wide differences reported for the same refractory by different laboratories⁷ using different methods. It has been recommended that these differences be eliminated by having the insulating fire brick all tested at the same laboratory under the same conditions.

Conductivity

23. Certain generalizations can be made regarding conductivity. It can be said, in general, that the conductivity is roughly proportional to the weight of the brick of a given type. It can

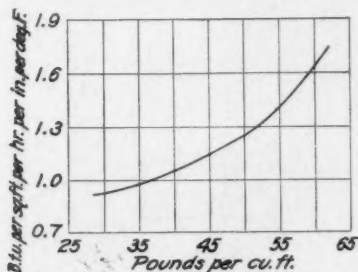


FIG. 4—RELATION OF WEIGHT TO CONDUCTIVITY (AT ROOM TEMPERATURE).

also be said that within certain limits the finer the pores the lower the conductivity. This is especially true at the high temperatures (See Fig. 2).

Weight

24. These brick, in general, weigh between 38 and 65 lb. per cu. ft., the largest number weighing between 40 and 50 lb.

Porosity

25. In a given type the conductivity is related to the weight rather definitely (See Fig. 4). It is interesting to note that the

⁷ Conference on Conductivity, Amer. Ceram. Soc., 1935; reports in subsequent Journals of the Society.

structure of these brick is so open that an air expansion porosimeter⁸ is the only way a true porosity can be determined. It varies between 65 and 85 per cent. Rueckel⁹ reports that the permeability of the different brick varies quite widely, depending upon the size of the cells and the cell communication. The permeability of the product made by the burning out process is high; the permeability of the bubble type of structure is lower.

Spalling

26. Insulating fire brick, as a class, tend to spall more than the better grade of dense refractories. This tendency is thought to be inherent in the structure of the brick and is certainly tied up with the steep temperature gradient in a wall of insulating re-

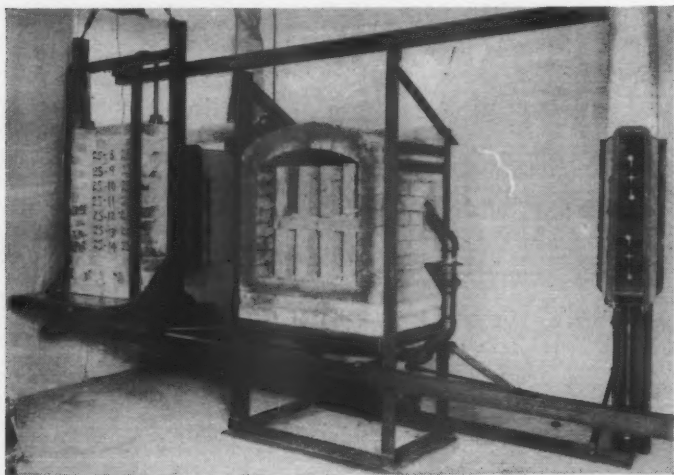


FIG. 5—THE A.S.T.M. SPALL FURNACE USED TO SPALL INSULATING BRICK.

fractories. It is not now known just what factors are involved in the spalling, but doubtless the cell structure and the uniformity and thickness of the cell walls are factors. It is thought likely that a refractory constituting a continuous phase is more likely to spall than one with an interrupted structure. Although there has been very little fundamental study of the problem, the refractories are now appreciably more resistant to spall than they were formerly.

⁸ A Simple Brick Porosimeter, Pressler, Amer. Ceram. Soc. Journal, Vol. 7, pp. 154-157.

⁹ Physical Properties of Some Insulating Brick, Walter C. Rueckel, Amer. Ceram. Soc., Vol. 18, No. 1, Jan., 1935.

27. The standard spall test method involving the use of a wall structure, while somewhat modified, will doubtless be used for the test. Mellon Institute is now gathering data which will later be used to write into a specification for the various services to which insulating refractories are likely to be put.

Strength

28. The strength of these refractories, while sufficient for the purpose for which they are used, is not all that could be desired. A crushing strength of 600 pounds per square inch is about the limit of the present product. Some of them will run as low as 100 pounds per square inch. This low crushing strength is not inherent in a cellulated body. We have made brick in the laboratory which had a crushing strength of well over 1000 pounds per square inch with a porosity of over 80 per cent. The relation of the transverse strength to the crushing strength is most erratic. In some cases the transverse strength is actually greater than the crushing strength, while in other cases the crushing strength is several times the transverse strength.

29. Some of the properties of insulating refractories are shown in the Table 1. The work is that of Dr. Rueckel¹⁰ in our laboratories. The conductivity values have been omitted from Rueckel's table.

ADVANTAGES OF INSULATING FIRE BRICK

30. While the advantages of insulating fire brick have been listed variously by different furnace builders, it is safe to say that the low heat storage capacity is a major item since it has been found that the time required for heating up a furnace built of insulating fire brick is less than one-third the time required for a furnace built of dense fire clay brick. It is claimed that the furnace is not only heated up much more rapidly, but that the heat penetration of the furnace contents is more uniform than in the case of dense fire brick furnaces.

Thermal Conductivity

31. Low thermal conductivity is, of course, the outstanding advantage of this type of refractory. Curves (Fig. 1) showing the conductivity of one complete line of insulating refractories are shown. The products of other firms do not differ widely from these

¹⁰ Bulletin Amer. Ceram. Soc., Vol. 13, No. 10, 1934.

values. The conductivity will vary with the material from which the refractories are made and will be roughly inversely proportional to the weight of the brick. The size and contours of the

Table 1
PROPERTIES—INSULATING REFRACTORIES

Samples	P.C.E. (cone)	Permeability cc. per sq. in.	Load Cold lbs. per sq. in.	Load Hot per cent subsidence 2250°F. 2400°F.	Weight per cu. ft. lb.	Shrinkage Linear per cent 2500°F. 2700°F.	Porosity (per cent)	Modulus of Rupture lbs. per sq. in.	Use °F.
A 34	.262	158	66	3.36	37.7	1.12	1.25	82	91 2800
B	..	..	4.59	11.02	57.0	..	..	..	2400
C 32	.136	508	11.68	24.07	47.7	6.12	6.90	75	209 2200
D 31	.181	186	2.57	15.25	38.1	5.20	..	78	101 2300
E 32	..	220	..	25.00	41.5	1.25	..	..	170 2300
F 23	.013	761	3.51	7.02	38.3	2.55	..	79	111 2000
G 23	.089	276	..	..	37.6	1.33	..	80	89 2200
H 34	.243	102	10.07	22.45	47.0	1.85	4.40	77	162 2100
I 31	.234	118	24.40	26.50	50.6	2.58	..	76	219 2200
J 31	.173	300	0.0	3.07	54.4	..	5.17	67	182 2600
K 28	.283	579	25.00	..	52.6	1.52	7.00	74	241 2200
L 31	.171	522	.92	8.78	61.2	2.25	6.00	68	301 2400
M 31	.280	1475	.00	.00	39.0	1.00	..	82	300 2700

pores and the cell structure will also have a bearing on the conductivity.

Furnace Construction

32. Aside from being a confiner of heat, the furnace construction is much simplified by using insulating fire brick. The low weight of the furnace enables it to be built on a floor that is entirely inadequate to support the weight of an ordinary furnace. We have two pottery kilns on the third floor of the Engineering Experiment Station at The Ohio State University, the floor design allowing for only 200 lb. per sq. ft. It would have been impossible to have built the furnaces of dense refractories on this floor design. These furnaces are used for heats up to 2500° F. The walls are but nine inches thick. Using the relatively fast firing schedule which we employ, we find that the kiln walls are cooler on the outside than furnace walls built of dense refractories 18 inches thick.

33. Another type of construction which is peculiar to light weight refractories is a type of suspended flat arch made of standard brick. We do not wish to infer that sprung arch spans are not feasible with this type of refractory. They have been used in spans of as much as 25 feet.

34. In the suspended flat arch construction the brick are suspended in a number of ways. Both Norton¹¹ and Keller¹² suggest that they can be strung on pipe run through holes bored in

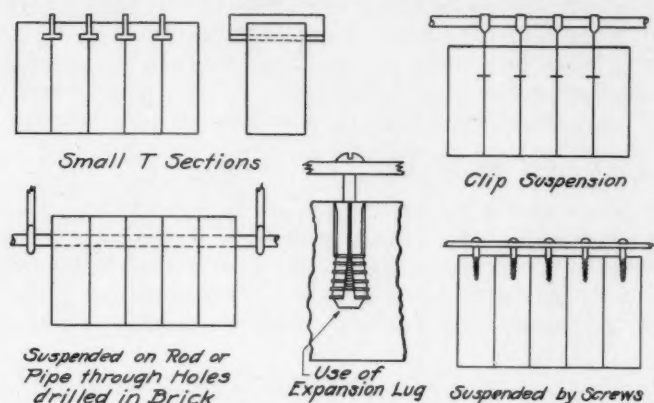


FIG. 6—SUGGESTED METHOD OF FLAT ARCH CONSTRUCTION USING INSULATING REFRACTORIES.

the brick, and that they can be held in place by screws. They can also be held by clips between the brick. We have used light T beams for the supports. Furnaces constructed with insulating refractories occupy less room and are built of much lighter steel construction than the ordinary furnace.

Periodic Furnaces

35. Whatever else the use of insulating refractories may be, it is quite evident from the nature of the product that its greatest usefulness is in periodic furnaces and especially in periodic furnaces that are operated on a short time schedule.

Use of Mortar

36. There has been considerable discussion relative to the use of mortar with this type of brick. It is agreed that if any mortar is used it should be a thin skin coating only. Some engineers use dry joints and have found that the practice gives satisfactory results. We presume that it will depend upon the particular furnace and somewhat upon the refractory whether mortar

¹¹ *The Manufacture and Use of the Insulating Firebrick in the United States*, F. H. Norton, *The Refractories Journal*, Feb., 1936, p. 59.

¹² *Application of Insulating Refractories to Industrial Furnaces*, J. D. Keller, *Amer. Refractories Inst. Tech. Bull.* 53.

joints are desirable with this type of brick. In the beginning it was thought that a facing of a refractory cement would increase the life of the refractory. Thick facings have been found unsatisfactory and are no longer employed. It is thought by some furnace builders that a very thin coating (less than 1/16 in.) will adhere to the refractories and give some advantage in operation. It was thought that a thin facing would cut down the permeability of the refractory, but this has not been borne out in practice.

Field of Applications

37. It is not the writer's purpose to discuss furnace construction since he is not a furnace builder. It is interesting to note, however, that successful installations have been built involving annealing and stress-relieving furnaces, heat treating furnaces, forging furnaces, brass melting furnaces, welding furnaces, equalizing furnaces, etc.

A WORD OF CAUTION

38. Just a word of caution must be added to this possibly too enthusiastic endorsement of insulating fire brick.

39. These refractories cannot be used in contact with slags. They are therefore unsuited for furnace bottoms. Even though they were to be made non-absorbent, which is a remote possibility, they, nevertheless, would have a very high surface shrinkage in contact with slags.

40. These brick have a very poor resistance to abrasion which would render them unsuited to certain furnace uses.

41. The fact that they are pervious to air could be a drawback in certain construction. This, however, can be taken care of in the furnace design.

42. There are some few services where the relatively low resistance to spalling might be a limiting factor in the use of insulating fire brick. This has, in general, not proved to be a drawback to their use.

SUMMARY

43. Insulating fire brick is that type of cellulated refractory that can be used in furnace linings with no protection from flame impingement. Refractory insulation is that type of cellulated refractory which is used as back-up for dense fire brick.

44. Cellulated refractories are divided into two general classes as above defined. The insulating fire brick is, in turn, subdivided into several classes depending upon the service temperature limits.

45. The outstanding properties of these brick are that they have a low heat capacity, thus enabling one to heat up a furnace rapidly, and that their heat conductivity is low, making them a good confiner of heat, in this way saving a large part of the fuel bill. In addition to these two properties they are light in weight, making possible a more simple furnace construction. The superstructure can be lighter and the furnace smaller due to thinner walls. They have an advantage over dense brick in that they can be cut with a saw so as to fit accurately into any furnace part. The property of being easily cut makes unnecessary many special shapes since suspended arches and the like can be made of standard brick.

46. Most furnace builders favor a thin mortar joint, although furnaces have been built with no jointing material. A thin surface coating is thought to give some service advantage.

47. The reheat test is the most valuable single test for this type of refractory and will in time limit a given product to its proper service.

48. These brick spall rather badly when tested as a single brick but when assembled in a panel they give a much better test. They are, however, not highly resistant to thermal spall.

49. These brick can probably be made much stronger than they are at the present time. Research work on this point is needed. The permeability of the brick can and should be reduced when service demands call for a low permeability.

50. The load test in its present form should not be required, since these brick have such a steep temperature gradient in the wall. A modified load test will possibly be suggested.

51. The P.C.E. test so dear to the hearts of all refractories men tells much less about the cellulated products than it does about dense refractories. Their failure is in structure rather than in actual fusion.

(Discussion of this paper will be found beginning on page 287.)

Insulating Refractory Brick—Their Properties and Application

By A. V. LEUN,* BETHLEHEM, PA.

Abstract

Insulating refractory brick, as their name implies, allow for their use in direct exposure to furnace heat. Their use in furnace construction allows for thinner walls than when using fireclay brick, besides resulting in excellent fuel economies. Due to their low heat content, furnaces built of this class of brick can be brought up to operating temperature much faster than when fireclay brick are used. The heat loss through these brick is considerably lower than through fireclay brick. In intermittently operated furnaces, where heat content of the furnace wall is a large factor, insulating refractory brick accomplish very high fuel savings over ordinary fireclay brick, besides allowing for greater production per furnace run. Certain precautions must be observed in using insulating refractory brick, such as coating their exposed face with a suitable high temperature cement, this to prevent gas passage through the brick and to increase the furnace efficiency. There are many brick of this type on the market some of which are not suitable for the temperatures claimed for them. When planning to use these brick, care should be taken choose the brick best suited for the job in question. Impro choice may result in shrinkage and spalling of the brick when employed in a furnace, resulting in early failure of the construction.

1. Insulating refractory brick may be defined as light weight brick capable of being exposed to furnace temperatures without having their efficiency appreciably impaired.

2. Previous to the introduction of this type of brick, furnace construction generally consisted of a firebrick lining from 13½ in. to 21 in. thick with or without an insulating medium between the outside of the brickwork and the furnace shell. For many years

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there had been insulating brick on the market used for backing up refractory brick. These brick had as their only function the decrease in heat flow from the furnace lining to the outside atmosphere, resulting in an appreciable fuel saving.

3. With the development of insulating brick for direct heat exposure it became possible to cut down the furnace wall thickness as much as 50 per cent and in some cases accomplish fuel savings as high as 75 per cent.

FACTORS GOVERNING FUEL REQUIREMENTS

4. In the design and operation of a furnace the fuel required for its operation is influenced by such factors as:

- (1) Tonnage of steel to be heated, etc.
- (2) Temperature of operation.
- (3) Type of operation, i.e., steady or intermittent.
- (4) Type of brick used in furnace construction.
- (5) Heat content of furnace walls.
- (6) Heat loss through walls.

Heat Loss Through Wall

5. The heat loss through a furnace wall and the heat content of the walls are dependant on the operating temperature, the construction employed and the brick used. The higher the operating temperature, the greater the heat content and the heat loss. Heat loss through a wall is determined by the formula

$$H = \frac{(T_1 - T_2)K}{x}$$

where T_1 = inside wall temperature
 T_2 = the outside or cold side temperature
 x = the wall thickness
 k = the conductivity of wall material
 H = Heat Loss

Heat loss, therefore, varies directly as the temperature difference between the inner and outer faces of the wall, the conductivity k and inversely as the wall thickness.

Heat Content of Wall

6. The heat content of a wall varies directly as the mean temperature of the wall, its specific heat and the density of the brick. As the density of the brick decreases, the heat content will decrease at any definite furnace temperature.

COMPARISON BETWEEN FIRECLAY BRICK AND INSULATING REFRACTORY BRICK

7. With these fundamental facts, a comparison between insulating refractory brick and fireclay brick as to their relative worths in furnace can be made. To aid in this comparison, four wall sections are shown in Fig. 1 with the necessary data on each. Tables 1 and 2 give additional comparative data.

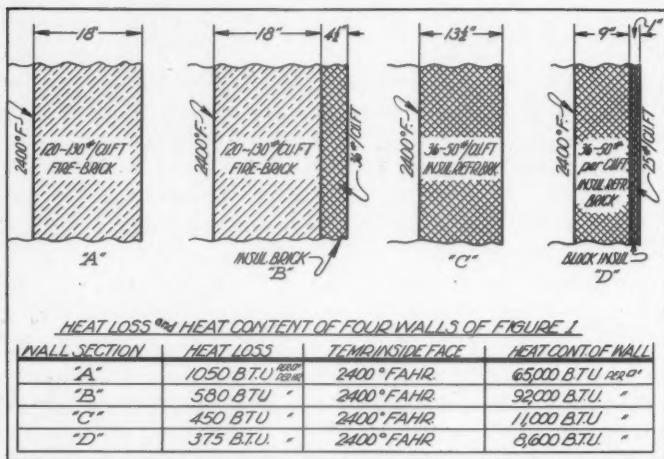


FIG. 1—COMPARISON BETWEEN INSULATING REFRACTORY BRICK AND FIRE CLAY BRICK.

Table 1

DENSITY AND RELATIVE HEAT STORAGE CAPACITY OF FIRECLAY AND INSULATING REFRACTORY BRICK

Type of Brick	Density lb. per cu. ft.	Relative Heat Storage Capacity
Fireclay brick	120 to 130	4.1
Insul. Refr. Brick A	48	1.84
Insul. Refr. Brick B	36	1.37
Insul. Refr. Brick C	52	1.99

Table 2

MEAN SPECIFIC HEAT OF FIRECLAY BRICK (N. F. NORTON)

Temperature ° F.	Mean Specific Heat B.t.u. per lb.
500	0.207
1000	0.225
2000	0.265

8. In these four wall assemblies, the same hot face temperature of brickwork is assumed, namely 2400°F . Wall section *A* is composed of 18 in. of firebrick. Wall section *B* is the same as *A* but with $4\frac{1}{2}$ in. of back-up insulating brick added. Wall section *C* consists of $13\frac{1}{2}$ in. of Refractory insulating brick while *D* is 9 in. of insulating refractory brick backed up with one inch of block insulation.

9. Studying these four typical wall assemblies many pertinent facts are most evident. In wall assembly *A*, where only fireclay brick is employed, the heat loss is 1050 B.t.u. per sq. ft. per hr. and the heat content of the wall per sq. ft. of surface is 65,000 B.t.u. In other words, it requires 65,000 B.t.u. of heat for every square foot of furnace area to bring the brick work in the wall up to equilibrium, and 1050 B.t.u. are lost from the furnace to the surrounding air for every sq. ft. of outside surface per hr. of operation. The addition of an insulating medium in the form of insulating brick to the outside of this 18 in. firebrick wall will retard heat flow to the outside atmosphere by over 45 per cent, but it causes a raising of the mean temperature of the firebrick wall and thereby raises the heat content of the wall to 92,000 B.t.u. per sq. ft., an increase of over 40 per cent.

10. In making the foregoing comparison between wall assembly *A* and wall assembly *B* no allowance has been made for the greater amount of heat passing through wall *A* as compared with the amount of heat passing through wall *B* during the heating up period, nor has any allowance been made for the increased time required for heating up furnace *A* as compared with the time for heating up furnace *B*. Moreover, in this connection, it should be noted that the layer of insulating material on wall assembly *B* will in general better the furnace performance by preventing the infiltration of air.

Wall Thickness

11. The use of an insulating refractory brick in place of the fireclay brick will allow for a lesser wall thickness, so wall section *C* consists of $13\frac{1}{2}$ in. of brick. In this assembly, the heat loss has been decreased to 450 B.t.u. per sq. ft. per hr., a saving of 22.4 per cent over assembly *B*, while the heat content of the wall has dropped to only 11,000 B.t.u., or an 88 per cent saving over *B*. To further save on heat loss from the furnace walls, the furnace might be constructed as in assembly *D*. Nine in. of insulating refractory

brick backed up with one inch of highly efficient insulating block. Here the heat loss has been dropped to 375 B.t.u. per sq. ft. per hr. and the heat content of the wall to 8600 B.t.u. This latter section represents a decrease of 90.6 per cent of the heat content of wall section *B* and a decrease of about 35 per cent in heat loss through the wall of section *B*. Besides the considerable saving in fuel, the thinner walls will allow for a smaller furnace with less actual area being covered.

Heat Content of Walls and Heat Loss Through Walls

12. The comparative effects of heat content of furnace walls and heat loss through the walls are dependant on the operation of the furnaces in question. Every time a furnace is brought up from the cold state to operating temperature, the walls will absorb an amount of heat equal to the product of the internal area of the walls in square feet times the heat content of the walls. Once these walls have reached equilibrium, the only loss of heat will be by conduction through the walls. If a furnace is operated intermittently, then the question of heat content in the walls is of paramount importance. If on the other hand, a furnace is in operation for long periods of time without a shutdown, heat loss through the walls is most important. In both cases, the use of insulating refractory brick will result in worthwhile savings, the former greater, however.

Rapid Heating of Furnaces

13. The use of insulating brick in place of fireclay brick will allow for more rapid heating of furnaces. Savings in time as high as 66 per cent over fireclay brick can be accomplished, however, due to their low heat content, the temperature variant through the brick when heating up is high. Too rapid a rise will result in too great a temperature differential between the hot surface of the brick and an inch or two back, resulting in subsequent spalling of the brickwork.

COMPARISON OF FUEL SAVINGS

14. A comparison of fuel savings that may be effected by the substitution of insulating refractory brick for fireclay brick is best shown by several problems.

Problem A

15. *Given a furnace to be built to operate intermittently at*

a temperature of $2400^{\circ} F$. Rather than give the internal dimensions of the furnace let us assume that its surface area equals 120 sq. ft. The fuel used is gas at a value of 25 cents per million B.t.u. Two furnace assemblies will be considered. One, using $13\frac{1}{2}$ in. of firebrick backed up with $4\frac{1}{2}$ in. of diatomaceous earth brick. The other arrangement is composed of 9 in. of insulating refractory brick backed up with 1 in. of block insulation. The furnace is to be used 12 hours per day, 3 days per week. What will be the comparative heat losses through the walls, the heat taken up by the brick and the saving resulting over a week's time by the use of the latter arrangement? A comparison of fire brick and insulating brick construction is given in Table 3.

Table 3

	Firebrick Construction	Insul. Brick Construction
Heat required to bring walls of furnace to equilibrium per sq. ft.—(B.t.u.).....	77,500	9,000
Total heat req. for 120 sq. ft.—(B.t.u.).....	9,300,000	1,080,000
Heat lost from walls by radiation per sq. ft.—(B.t.u.)	670	375
Total heat lost from walls per day—(B.t.u.)...	964,800	540,000
Heat lost per day into walls or through walls—(B.t.u.)	10,264,000	1,620,000
Cost of fuel lost in walls—(Dollars).....	2.56	.405
Saving per day in favor of insulating refractory brick construction	\$2.15	
Saving per week	\$6.45	

16. A saving in time required for heating up both types of construction results in approximately 2 hours saved in favor of the insulating brick construction. If this was turned into increased production, a greater rate would be turned out by the more efficient furnace resulting in a lower unit cost. In this furnace, the operation being irregular, the great saving is effected by the low heat content of the insulating brick walls.

Problem B

17. Given a furnace to be built for continuous operation and to operate at a face temperature of $2400^{\circ} F$. The fuel to be used is gas valued at 25 cents per million B.t.u. Two furnace assemblies are under consideration. One, using $13\frac{1}{2}$ in. of firebrick backed up with $4\frac{1}{2}$ in. of diatomaceous earth brick and the other using 9 in. of insulating refractory brick backed up with one inch of block insulation. The internal area of the furnace equals 1800

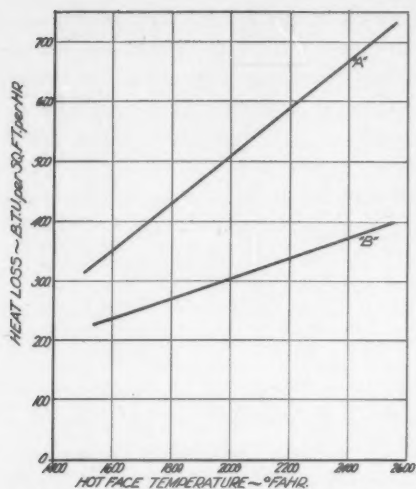


FIG. 2—HEAT LOSS THROUGH FURNACE WALLS IN B. T. U. PER SQ. FT. PER HR.—CURVE "A"—FOR 13½ IN. FIRE BRICK PLUS 4½ IN. INSULATING BRICK—CURVE "B" FOR 9 IN. INSULATING REFRACTORY BRICK PLUS 1 IN. BLOCK INSULATION.

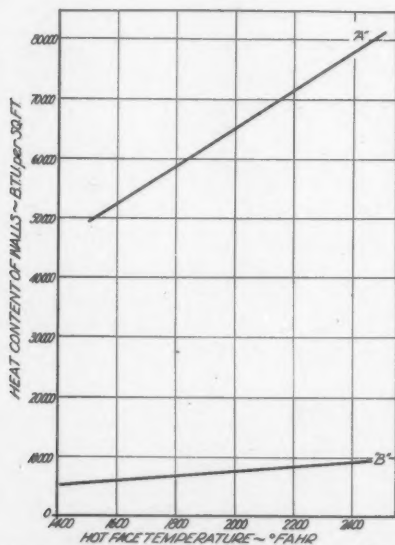


FIG. 3—HEAT CONTENT OF FURNACE WALLS IN B. T. U. PER SQ. FT.—CURVE "A", 13½ IN. FIRE BRICK PLUS 4½ IN. INSULATING BRICK—CURVE "B", 9 IN. INSULATING REFRACTORY BRICK PLUS ONE IN. BLOCK INSULATION.

sq. ft. What will be the comparative heat losses and fuel savings for one month's operation? A comparison of firebrick and insulating refractory brick construction is given in Table 4.

Table 4

	Firebrick	Insulating Refr. Brick
Heat required to bring wall of furnace to equilibrium per sq. ft. (B. t. u.)...	77,500	9,000
Total heat required for bringing walls to equilibrium (B. t. u.).....	139,500,000	16,200,000
Heat loss through walls per sq. ft per hr. (B. t. u.).....	670	375
Heat loss through walls per 24 hrs. (B. t. u.).....	28,944,000	16,200,000
Heat loss for 30 days (B. t. u.).....	868,320,000	486,000,000
Total heat loss per 30 days (in millions B. t. u.).....	1,007.8	502
Cost of fuel (Dollars).....	252.00	125.50
Saving in fuel cost per month in favor of the insulating refractory brick, \$126.5		
Saving in fuel cost per month in favor of the insulating refractory brick, 50 per cent.		

18. Comparing the two furnace problems relative to the savings effected by decreasing heat content and heat loss, the insulating refractory brick effect a saving of \$2.15 per run of 12 hours in the first case. Of this, 95 per cent is saved in the lowered heat content of the walls. In the second comparison, where operation is steady, a saving of \$126.50 is effected by using the insulating refractory brick over a 30 day run. Of this, 24 per cent is realized in the reduced heat content of the wall, 76 per cent being saving in lowered heat loss through the walls.

19. To further illustrate the value of insulating refractory brick let us refer again to Fig. 1 showing four different wall assemblies. Let us assume that these represent four furnaces of 1000 sq. ft. wall surface each. In Table 5 is tabulated the values of heat loss through, and heat stored in the walls.

Table 5

Furnace Wall of 1,000 Sq. ft. Surface	A	B	C	D
No. of firebrick in assembly.....	25,500	25,500	.....	.....
No. of Insulating Refr. Brick.....	.....	6,400	21,000	14,000
Sq. ft. of block insulation in walls.....	.....	.....	.....	1,000
Cost of Brick*.....	.....	.....	.....	.....
A—Firebrick (dollars).....	73.00	73.00	.....	.....
B—Insulating brick (dollars).....	.....	112.00	.....	.....
C—Insulating Refr. Brick (dollars).....	.....	.....	149.00	149.00
D—Block (per sq. ft. (dollars).....	.....	.....	.....	0.18
Cost of total wall—firebrick (dollars).....	1,860.00	1,860.00	.....	.....
Insulation (dollars).....	.....	715.00	3,129.00	2,266.00
Total (dollars).....	1,860.00	2,575.00	3,129.00	2,266.00
Value of heat loss per hr. through wall @ 25c per million B. t. u. (dollars).....	0.282	0.145	0.11	0.094
Million B. t. u. stored in walls.....	65	92	11	8.6
Value of heat stored in wall (dollars).....	16.20	23.00	2.75	2.15

*Cost of Brick includes freight per M and laying brick @ \$15 per M.

COST OF HEAT LOSS

20. The value of heat loss may be shown as indicated in Table 6 for a furnace (A) operating 600 hours per month and shut down once each week and for a furnace (B) operating 200 hours per month (twenty-five 8-hour turns) and shut down 25 times per month. The furnace production is 1000 tons and 333 tons respectively.

Table 6

Furnace A—Shut Down once each week.—600 Hours Operation per Month with Production of 1000 Tons.

Furnace Wall of 1,000 sq. ft. surface	A	B	C	D
Value of loss (through furnace walls) (dollars).....	157.00	87.00	68.00	56.00
per month (In furnace walls) (dollars).....	85.00	92.00	11.00	8.60
	222.00	179.00	79.00	64.60
Value of heat lost per ton of Product (dollars).....	0.222	0.179	0.079	0.064

Furnace B—Shut Down 25 times per Month—200 hours operation per month with production of 333 tons.

Furnace wall of 1,000 sq. ft. surface	A	B	C	D
Value of loss (through furnace walls) (dollars).....	52.00	29.00	22.00	19.00
per month (in furnace walls—25 shutdowns) (dollars)...	405.00	575.00	69.00	54.00
Total (dollars).....	457.00	604.00	91.00	73.00
Value of heat loss per ton of Product (dollars).....	1.37	1.80	.27	0.22

PROPER CHOICE OF BRICK

21. Having shown the economies that can be accomplished by the use of suitable insulating refractory brick in furnace construction, the proper choice of brick is of importance. There are many brick of this type on the market, some good, others not as capable of service at high temperatures as claimed for them.

22. Brick of this type should have the following properties:

- (1) They must have suitable load carrying ability.
- (2) They must withstand the temperature of operation without shrinkage.
- (3) They must be spall resistant.
- (4) They must take a face coating of cement.
- (5) They must hold this coating during service.

23. In the author's experience with many brands of insulating refractory brick, the first item can be passed over since none has been found to be deficient in this respect.

24. To withstand shrinkage under service conditions, requires that the brick be burned at a temperature higher than that of operation. Failure to do this will result in wall shrinkage with a subsequent impairment of the efficiency of the brick. Under reducing atmospheres, brick apparently satisfactory from the stand-

point of shrinkage, will develop this condition 150 to 200° F. below the temperature claimed. Therefore, a reasonably high factor of safety must be allowed between the temperature of operation and the maximum working temperature of the brick as claimed by the manufacturer. It has been found by the author that some brick recommended for service at as high as 2600° F. will develop considerable shrinkage at temperatures as low as 2200° F.

25. It is needless to go into detail when discussing the resistance to thermal shock required of such brick. For efficient and economical operation, all brick must show good resistance to spalling. If brick are used at temperatures higher than they are fitted for, the inner face will shrink, resulting in strains being set up in the brick, which will ultimately result in a spalling off of the face.

FACE COATING

26. There has been a great deal of controversy among manufacturers of insulating refractory brick with regard to the application of a face coating to the inner walls of a furnace built of these brick. It is highly recommended and in fact most necessary that this be done, especially so if the furnace is to work under pressure.

Table 7

COMPARATIVE DENSITIES AND PERMEABILITIES OF FIREBRICK VS INSULATING REFRACTORY BRICK

Brick	Density lb. per cu. ft.	Time to pass 2000 c.c. air through brick at 0.5 lb. per sq. ft. pressure
		minutes
Firebrick.....	130	7.5
Insul. Brick A.....	31	0.5
Insul. Brick B.....	48	1.25
Insul. Brick C.....	52	1.5

27. In comparison to heavy fireclay brick, insulating refractory brick are porous and offer little resistance to gas passage through them. This condition, if allowed to exist in a furnace, would permit of heat loss by convection through the brick. The spraying or painting of a refractory coating on a furnace wall built of these brick will prevent any penetration into the brick and in addition will increase the efficiency of the furnace by reflecting heat rays back into the furnace. This will result in a lower temperature in the brickwork, lower heat content and less heat loss.

28. It is very important that insulating refractory brick be of such a texture that they will hold any coating applied. Too fine a texture will prevent actual locking of the coating into the pores of the brick and such a coating will ultimately peel off. Brick of this type of surface are not recommended for use.

29. A word about the coating to use would not be amiss at this point. The use of an improper material may impair the value of the brick employed. It is not just necessary that a coating material adhere and soak into a furnace wall. It must have fired characteristics not too different from the brick. Too high a shrinkage in such a material will result in ultimate peeling off of that part of the brickwork penetrated by the coating material. For a coating medium, the author would suggest an air setting, low shrinking, high temperature cement. Most of the air setting high temperature cements on the market today are not suitable for such an application due to their excessive shrinkage.

30. The application of a coating may be accomplished by either spraying or brushing it on to a depth of not over 1/16 in. in thickness. It is necessary that the initial application penetrate into the surface pores of the brick.

TESTING REFRACTORY INSULATING BRICK.

31. A word as to the methods employed by the author in testing this class of brick.

Permeability

32. To test for permeability, the brick are paraffined on all sides except an area on each of the $9 \times 4\frac{1}{2}$ in. sides, the size of the A. F. A. permeability tube. On the upper side, a tube is sealed to the brick and connected to the permeability apparatus. The time required to force 2000 cc of air through the brick at 0.5 lb. per sq. in. pressure is then measured.

Shrinkage, Spalling, Etc.

33. In testing for shrinkage, spalling, taking and holding a coating, the brick are set into a panel with their $9 \times 2\frac{1}{2}$ in. faces exposed to the heat. The wall thickness of the panel being $4\frac{1}{2}$ in. The outside of the panel is covered with a monolithic insulating cement, in our case, slag wool cement being used, it being applied 2 in. thick. All brick are laid with a good high temperature cement. The panel after being dried is slowly brought up to a

predetermined temperature and held there for a period of 24 hours. The panel is removed and after cooling the brick are measured for shrinkage. The panel is then placed in position again and raised to a higher temperature, where the same procedure is repeated. The temperature can thus be found past which shrinkage of the brick will occur.

Holding Coating and Resisting Thermal Shock

34. To determine the ability of the brick to take, and hold a coating and to resist thermal shock, a new panel is set up similar to the one just described. The panel is sprayed with an especially prepared high temperature cement and then placed in position in the front of the furnace. The temperature is raised to a point about 50° F. below that temperature where shrinkage was found to start and maintained until the panel reaches equilibrium in its heat absorption. It is then swung over in front of a fine water spray. Before spraying, the panel is observed to determine

Table 8

COMPARATIVE DATA ON 10 BRANDS OF INSULATING REFRACTORY BRICK

Brand	Density lb. per cu. ft.	Perm.* Min.—Sec.	Per Cent Linear Shrinkage				Ability To	
			2200°F	2400°F	2600°F	Spalling Per Cent	Take A	Hold A
A.....	38.2	1 30	.....	.....	1.2	.....	good	good
B.....	37.1	1 20	.....	2.8	DnR**	.....	good	good
C.....	33.5	1 30	.....	.....	4.2	3.5	good	good
D.....	60.5	1 20	.....	.....	.....	.....	good	good
E.....	41	30	.....	3.0	DnR**	40	poor	poor
F.....	40	1	.....	.....	DnR**	35	poor	poor
G.....	44.5	1 15	1.75	7.0	DnR**	65	good	fair
H.....	47	1 25	.....	1.0	4.0	8	good	good
I.....	49	1 15	.....	4.3	DnR**	100	good	poor
J.....	67	1 40	.....	1.4	2.6	20	fair	fair

*Time required to pass 2,000 c.c. of air through brick at 0.5 lb. per sq. in. pressure.

**Did not Run.

the degree to which the coating was held. The spray is then directed against the brick for 45 seconds after which the panel is returned to the furnace for 15 minutes before spraying again. This procedure is repeated for 15 cycles. The panel is allowed to cool and the brick removed, the coating being observed again as well as the degree of spalling occurring.

35. From a study of Table 8, tabulating comparative data on 10 brands of insulating refractory brick, can be noted that all

brick are quite permeable, making necessary their face coating when used in a furnace. Of the 10 brick tested, only two showed ability to withstand appreciable shrinkage at temperatures of 2600° F. or above. Five showed high spalling and three were of such a texture as to make it impossible for a coating to adhere in service. For this reason, the author recommends care when choosing a brick for the lining of a furnace, especially when its temperature of operation is above 2400° F. and it is to be run intermittently.

CONCLUSION

36. The application of insulating refractory brick to furnaces such as forge, carbottom, reheating and treatment will result in very great fuel savings. Where slag attack or abrasion is a factor, the use of fireclay brick is advised in those wall sections where these attacks occur. Insulating refractory brick are rapidly eroded and worn away by either slag attack or abrasion.

37. It is recommended that all brick be layed and sprayed with a suitable high temperature cement. Care should be exercised to allow sufficient room for expansion in the walls.

38. The use of suspended insulating refractory brick roofs has become an accepted fact. Due to their texture, it is recommended that the suspension medium be in the brick. External suspension of the brick will cause early failure.

39. The operation of a furnace built of this class of brick is different than with a fireclay construction. When raising the temperature of a furnace built of insulating brick, far less actual heat input is necessary than when using fireclay brick for the same temperature increase. When cooling down, fireclay brick, having a high heat content, will allow for a slower furnace temperature drop than will insulating refractory brick. Where a slow drop is desired, it is necessary to maintain the fuel input higher with insulating brick than with fireclay brick.

40. While this type of brick is in service in many plants, there are still a large number who have had no experience with them. To these, the author recommends their trial. They present opportunities for great fuel savings and increased production.

(For Discussion see Pages 287 to 292)

DISCUSSION

NOTE: *The discussion reproduced here pertains to the two papers on insulating refractories by Dr. G. A. Bole (Page 261) and A. V. Leun (Page 274).*

J. L. ALLISON, JR.¹ (*Written Discussion*): Dr. Bole has touched upon a subject vital to manufacturers and users of insulating firebrick when he mentions the variations in thermal conductivity of the same refractory as determined by different laboratories. All manufacturers are agreed that such variations exist, but they are not agreed upon what standard method should be used to eliminate this undesirable situation. Until such agreement is reached, the user of insulating firebrick is placed in a difficult position when attempting to evaluate the comparative conductivities of the various brands, each of which is tested according to different methods. Dr. Bole is to be commended for bringing out this point, since a full discussion of the subject may be of assistance in hastening the adoption of a standard method of test.

We question the necessity for developing the high cold crushing strengths mentioned by Dr. Bole. The value of an insulating firebrick is in its low thermal conductivity and low heat storage. If the strength is sufficient for the purpose for which it is used, and the brick has low shrinkage and high resistance to spalling, the reason for prosecuting development of higher cold crushing strengths is not clear. It has been our experience, as borne out by test results in Table 1 of Dr. Bole's paper, that some of the insulating firebrick on the market having the highest cold crushing strengths are the least resistant to deformation under load at elevated temperatures. Since the refractory material is to be used under high temperatures, it would seem more logical to develop higher hot load bearing strength. Advantage can be taken of this in furnace design whereas cold crushing strength which falls off rapidly under temperature is of no particular value.

While it may be true that insulating firebrick, as a class, tends to spall more than the better grade of dense refractories, there is a wide variation existing between the spalling resistance of the various brands on the market, and for this reason, it is essential to investigate thoroughly the comparative spalling resistance of the brands available to insure the selection of the most suitable one. Undoubtedly, the steep temperature gradient existing in insulating firebrick accentuates spalling tendencies. This may be remedied to some extent by secondary insulation to make the gradient less steep, and by slower heating up when the wall has little or no residual heat from a previous run.

Mr. Leun's paper brings out in a very clear and logical manner the reasons for the operating savings resulting from the use of insulating firebrick. Over a period of years, it has been our experience that the use of insulating firebrick will reduce operating costs and increase operating efficiency in almost every type of operation in the metallurgical field where

¹The Babcock & Wilcox Co., Chicago.

this class of refractory has the required physical properties to warrant its application.

We were particularly interested in the tests described by Mr. Leun to determine the physical properties of the various brands of insulating firebrick. The Babcock & Wilcox Company decided at an early stage in development of insulating refractories that low conductivity and weight should be stressed to obtain the maximum thermal economy even though such a type of material had a relatively low cold crushing strength. The reasoning behind such a decision was that so long as sufficient strength was provided at operating temperatures to allow the installed brick to form a stable structure, excess strength at the sacrifice of thermal efficiency was not justified. The wisdom of such a decision is borne out by Mr. Leun's statement that he has found none of the insulating firebrick deficient in load bearing ability.

The panel spalling test, as described by Mr. Leun, is unusually severe and certainly brought out deficiencies in spalling resistance. From Table 8 of Mr. Leun's paper, however, we see that three out of the ten brands tested show no spalling loss. This indicates that certain light weight refractories have a structure which is far more resistant to spalling than others.

Mr. Leun has noted that rapid heating results in a sharp temperature differential in the brick, thus setting up spalling stresses. There are undoubtedly a number of installations where the life of insulating firebrick, particularly in the arch, could be increased by not taking full advantage of their quick heating characteristics, for the reason stated by Mr. Leun. In our opinion, this is particularly true of furnaces operating at temperatures above 2000° F. when started up cold, or after a weekend shutdown. Secondary insulation on the arch should be of benefit because it insures less of a temperature drop between the hot and cold face of the brick under equilibrium conditions and causes the brick to retain more heat during a shutdown. By retaining more heat in the arch, the temperature drop through the brick will be less severe, thus reducing the severity of the spalling stresses.

In conclusion, we feel that this paper is a very worthwhile contribution to users of insulating firebrick.

H. M. CHRISTMAN² (*Written Discussion*): Mr. Leun's paper is an excellent piece of work of special interest, especially since it comes from an operating man, and a representative of a company which began using insulating refractory brick about 1928. It represents a summation of many technical theories put in graphical, easily usable form, due to the comparative nature of his results. We trust that it will vindicate some of the refractory insulating people who have been referred to as theorists and enthusiasts in the past when they talked about saving 50 to 75 per cent of fuel, cutting heating cycles in half and increasing production.

Dr. Bole treats more from the ceramic and technical aspect. His data are based on Dr. Reuckel's work. However, since then, many improvements and changes have been made in the various refractory products tested since that date.

² Ceramic Engineer, Massillon Refractories Co., Massillon, O.

There is naturally some disagreement between Dr. Bole's and Mr. Leun's conclusions. Probably chiefly due to their viewpoint, but after all "The proof of the pie is in its eating."

I heartily endorse the use of a refractory coating on refractory insulating brick. It reduces penetration of hot gases and presents a smooth, heat reflecting surface which increases the efficiency, although the actual amount probably has not been determined.

The mistakes and mis-applications which have been made in refractory insulating brick are largely due to the lack of experience of the manufacturers and their haste to sell their product without proper engineering and development. The proper application of refractory insulating materials is an engineering problem, not a brick selling problem.

Additional hidden economies which Mr. Leun has intimated, exist when the production of a furnace is doubled without increasing the physical size, floor space, supervision or mechanical operating equipment, due to the reduction of overhead per ton of product furnished.

The merits of using a one component wall is clearly brought out by Mr. Leun's charts. In annealing work, we are interested only in getting the necessary number of B.t.u. in the furnace to do the work as quickly as possible and then cool the furnace as quickly as the product will permit. The use of secondary insulating material tends to dam up or retard the removal of the B.t.u. from the furnace in cooling.

Lastly, have you ever considered how accurately the dollars coming into your plant are disbursed and outgo balanced against income? These papers very forcibly bring out the great economies which might be effected by auditing your incoming and outgoing B.t.u.'s for B.t.u.'s really represent dollars.

MEMBER: I wonder if the insulating brick do not speed up the corrosion of the refractories? For instance, with an electric furnace (my experience has been in the cupola melting zones and the ladles—I have not had any experience with a Bracklesburg) the insulating brick has speeded up the corrosion of the refractories. In other words, the furnace needed water cooling rather than insulation. I wonder if I am correct in that deduction?

MR. LEUN: The minute you back up any brick lining with a layer of insulating brick you raise the mean temperature of that wall and you also raise its hot face temperature. If it is necessary to reduce the fuel input in order to maintain the same hot face temperature as previously, unless you decrease this fuel input you will melt and erode the wall more rapidly. As an illustration, in our Bethlehem plant, we have 18 open-hearth furnaces completely insulated. We decreased the fuel input in those furnaces so that we have the same face temperature now after insulating that we had before we insulated them. However, in the Detroit furnaces and the furnaces you mentioned, it would be pretty difficult to maintain that temperature and in many cases you will speed up the corrosion with less refractory life. But those are special cases. I was dealing with forge furnaces, reheating, car bottom furnaces, and core ovens—in other words, where you are treating steel or heating it up preparatory to rolling or other mill operations.

MEMBER: That is what I assumed. We kept the temperature just high enough in the furnace so that it was near the breaking down point of the refractory that we used.

MEMBER: In connection with those four furnaces on which the figures of operation were given by Mr. Leun, is the same construction of refractory used on the wall?

MR. LEUN: I might give you a little comparison. We recently completed a forge furnace 15 by 20 ft. Beside it is another furnace of the same size built of fireclay brick. The furnace built of fireclay brick takes 15,000 cu. ft. of coke oven gas and 12,000 cu. ft. of blast furnace gas per hour. The furnace built of insulating refractory brick with suspended insulating brick roof and completely lined takes between 12,000 and 14,000 B.t.u.'s of coke oven gas only. There is a saving of 2000 to 3000 cu. ft. of coke oven gas and 12,000 cu. ft. of blast furnace gas per hour. The furnaces are operated exactly the same, so you can evaluate and note the savings that are effected.

MEMBER: Mr. Leun, do you think it would be economical to rebuild a furnace I have in mind with insulating brick? It operates 8 hours and is then shut down for 16 hours. It operates at a temperature of about 2300° F.

MR. LEUN: The furnace you describe should be constructed of insulating refractory brick. Each time you light up, you start with a cold furnace. The firebrick wall, backed up with insulation, will require approximately 80 per cent more heat than an insulating brick wall, before reaching equilibrium. This means a larger fuel input into the walls and a larger time delay before the furnace reaches operating temperature. The use of an insulating refractory brick in this furnace would allow for thinner walls, a fuel saving possibly as high as 50 per cent and increased production due to faster heating.

MEMBER: I have the furnace built now of high temperature fire clay brick backed up with insulating brick.

MR. LEUN: That is putting the horse behind the cart. Such a construction is not recommended for intermittantly operated furnaces.

DR. BOLE: I believe we are in agreement on everything with the single exception of the facing, which has nothing to do with the refractory, but only with its service. Mr. Leun's conclusions are doubtlessly correct in the service which he describes and with the refractory used. I am a college professor. I only know what I am told. Mr. Leun's charts teach that some refractories do not hold the coating as well as do others. It may be that a furnace built from refractory that will not hold its surface coating is not satisfactory when coated. The refractory that holds the coating probably benefits from it. There is a vast difference of opinion as to what the coatings should be. Some furnace builders prefer a coating that will glaze and some prefer a non-glazing coating. It probably depends upon the type of melting and the temperature. We have tested brick in our laboratories coated with refractory cements. There was very little difference in the permeability of the coated and uncoated bricks. The coating application was cold, of course. You will notice in the table that I gave that there was as much as ten times the permeability

in some of the brick as there was in others. The answer, then, may lie in those two things: high permeability brick and brick which will retain the coating. You will have quite an advantage in brick which do retain the coating. The type of coating must be given consideration—whether it is a glazing or a non-glazing coating. I should presume that anyone benefitting from coating would use it and anyone gaining no advantage would drop it.

MR. LEUN: Mr. Chairman, there is one other point I want to bring out. I believe I described it in my paper. We not only put the face coating on to stop heat from penetrating into the brick, but for two other reasons: First, if you are heating steel, there are particles of iron floating around in that furnace atmosphere. They will be driven back into the brick. This coating will decrease such penetration. Sooner or later the coating may be destroyed. It is a great deal easier to replace the coating than the brick.

Secondly, 80 per cent of the heat transmitted to a furnace lining is transmitted by radiation, not convection or conduction. A glazed or semi-glazed surface is not a good absorber of radiated rays. If you are an open-hearth man, you look at the checker brick when the furnace is down for repair. If these brick are glazed, you will remove them, replacing them with new brick. When a surface takes a glaze, its emissivity is greatly impaired. With a glazed coating, that surface decreases the heat input in that wall from 7 to 20 per cent. It will actually reflect heat rays back into the furnace. Semi-super refractory clay brick are harder to glaze in ordinary furnace operation than first quality fireclay brick. Both brick may have the same conductivity, but when you put them into the furnace wall you will find the fire clay brick will conduct less heat than will semi-super refractory clay brick. The fire clay brick has developed a glaze and the other has not. It will therefore absorb less heat than the latter, conducting less to the outside air.

That is the main reason we apply a coating, to increase the efficiency of the furnace by developing a glaze.

GEORGE A. BALZ²: (*Submitted as written discussion*) Professor Bole has ably presented a subject which gives every promise of becoming of increasing interest to users and manufacturers alike. Within the comparatively brief period during which insulating or cellulated refractories have been made available to the consumer, their use has expanded to a degree which probably was not anticipated by the manufacturers who pioneered in this field.

As in several instances in the past, where the introduction of a new refractory material has been involved, there will in all probability be cases where the material will be erroneously installed, with consequent dissatisfaction and perhaps complete failure.

In the writer's opinion cellulated refractories should not be used in places where slag-action, in any degree, is involved, at least until such time as a permanent refractory coating has been perfected, which actually, and for a reasonably extended period, effectively closes the highly porous structure of the refractory against attack by slag, flame and gas.

² Seaboard Refractories Company, Perth Amboy, N. J.

Although the crushing strength of the cellular refractory is low in comparison with the conventional clay refractory, it appears that the deficiency almost provides its own remedy, in that the compressive stresses imposed upon it solely by the force of gravity are correspondingly reduced.

Where thermal expansion forces are involved, however, the problem is one which should receive the most careful consideration of the designer, as it sometimes occurs that expansion forces, which normally produce compressive strains, ultimately develop resultants leading to tensile stresses in the refractory. The cellular refractory, as produced today, can hardly be considered a material of high tensile strength.

Experience in the manufacture of this material has shown the possibility of producing special shapes of large dimensions, within reasonably close size tolerance, without cutting or grinding.

It appears to the writer that at the present time there is sadly needed some procedure dealing with the subject of uniform laboratory tests and methods therefor, which may be applied to the cellular product in order that light may be shed upon the questions of quality and grade.

Although there undoubtedly are points where the desirable characteristics of cellular refractories coincide with those of the conventional product, it would seem that the most rapid progress in the matter of writing specifications and methods of tests for their determination, would be made, if the problem were attacked untrammelled by any characteristics possessed by the conventional type of clay refractory.

Among possible tests, the following suggest themselves as capable of revealing the properties of the cellular refractory.

1. Thermal conductivity.
2. Softening and melting temperatures, respectively, of the body as a refractory, not as a cellular structure, thus eliminating the questions of temperature gradient and cell walls.
3. Spalling, by panel test (not dipping).
4. Thermal expansion.
5. Volume changes under superficial and complete reheat.
6. Permeability.
7. Density.
8. Cold crushing strength.
9. Cold modulus of rupture.

The economy of installing insulating refractories in furnaces which are continuously heated is probably open to debate; in such case, heat storage and minimum heat flow are important considerations. The cellular refractory is not competitive as a heat insulator with high grade refractory diatomaceous-earth insulating brick.

Cast Iron as Affected by Coke Size in Cupola Melting

By J. A. BOWERS* AND J. T. MACKENZIE,** BIRMINGHAM, ALA.

Abstract

In an effort to secure more definite information as to the effect that the size of coke has on the melting of iron and and its influence on the physical properties of the castings, the authors ran a series of tests in a 21-in. diameter cupola, using four sizes of coke ranging from 1 to $\frac{1}{4}$ in. Details of the test are reported, including a complete record of each heat and the chemical and physical data on the iron from each ladle. A series of charts present the results and show the fluctuation of sulphur, silicon, manganese and carbon, and temperature changes and trends in physical properties. While the authors state that the results are considered applicable to 21 in. cupola operation only, the trends are of interest from their possible application to general cupola melting. Some conclusions reached were that sulphur and carbon increase and silicon and manganese losses decrease with each decrease in coke size. The most outstanding conclusion, in the opinion of the authors, is that after the first eight to ten ladles, the changes in the elements are practically unaffected by changes in coke size.

1. To determine the effect which the size of coke might have on the chemical analysis and properties of iron as melted in the cupola, a series of test heats were planned and carried out in the research department of the American Cast Iron Pipe Co. The results obtained in this investigation, presented in this paper, show some interesting data and conclusions of general interest to the gray iron foundry industry.

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** Chief Chemist and Metallurgist, American Cast Iron Pipe Co.

NOTE: This paper was presented before the Gray Iron Session of the 41st Annual Convention, Milwaukee, Wis., May 4, 1937.

EQUIPMENT.

2. The cupola used in all of these experiments was of the portable type lined to 21-in. inside diameter. The tuyeres enter the cupola at a height of 5-in. from the bottom of the tap hole and on opposite sides, each being 90° removed from the tap hole. The tap hole was 1 1/4-in. in diameter. Details of cupola construction were as described in a paper¹ presented before the 1936 meeting of this association.

3. Other equipment used consisted of the following:

1. Leeds and Northup disappearing filament optical pyrometer with adjustable grid for high range temperature readings.

2. U-tube water manometer calibrated in inches.

3. Two, 150 lb. hand ladles.

4. 500 lb. capacity Fairbanks scales for weighing iron and coke charges.

5. Five coke screens with openings as follows: 5-in. square, 3-in. diameter, 1 1/2-in. diameter, 1-in. square, and 1/2-in. square.

RAW MATERIALS AND PROCEDURE

4. Raw materials charged into the cupola were selected and prepared in the same manner for all heats.

Coke

5. All coke was taken from the same car and screened to four sizes; through a 5-in. screen on a 3-in. screen, through a 3-in. on a 1 1/2-in. screen, through a 1 1/2-in. on a 1-in. screen, and through a 1 1/2-in. on a 1/2-in. screen. The 1 1/2 x 1/2-in. coke was used for one heat only (Table 1) and made up the entire bed and charges.

6. In experiments on all of the other sizes, coke of standard foundry size, 3-in. and up, was used up to 12-in. above the tuyeres, and the remaining coke which includes the rest of the bed and a charges was the size specified for each test. Each coke charge weighed 12.5 lb., and 2 lb. of dolomite was used as a flux for every charge.

7. The analysis of the coke was as follows: Volatile matter, 0.5 per cent; fixed carbon, 90.8 per cent; ash, 8.7 per cent; moisture, 0.9 per cent; sulphur, 0.6 per cent; shatter, 82; porosity, 49.

¹ Johnson, H. V., and MacKenzie, J. T., "Effects of Tuyere Heights on Carbon Pick-Up in the Cupola," TRANS. A.F.A., vol. 44 (1936), pp. 178-190.

Iron Charges

8. The iron charges were made up of cast iron pipe about 0.4-in. thick broken to an average size of approximately 8 x 4-in. Complete chemical analysis was made on each pipe and the allowable variation in silicon and carbon content of the pipes used for the charges was limited to approximately 20 points for each heat. The proper quantity of this iron sufficient to operate one heat was thoroughly mixed and weighed into 125 lb. charges.

The Coke Bed

9. Forty inches of coke bed burned red, a short warm-up of 3 to 5 minutes, and additional green coke to 50-in. above the tuyeres was the general order of procedure.

Charging and Melting

10. Charging of coke and iron, as described above, began immediately after preparation of the bed, and the cupola was filled to the top of the stack. This level was maintained throughout each heat; coke following the last iron charge kept the wind pressure and furnace melting rate normal until the blower was shut down.

11. At the beginning of the heat, the tap hole was left open until iron was melted, this being indicated by a continuous spray of iron sparks coming from the tap hole. Then the blast was shut off and the tap hole stopped with blacking. This elapsed blowing time was included in determining the duration of the heat. Blowing was immediately resumed and the cupola was tapped at a time when the basin was estimated to be full depending on the melting rate of the size of coke used.

12. Iron flowed continuously into hand ladles and an attempt was made to fill these ladles with the same amount of iron as that contained in one charge. Stream temperature readings were made at four intervals during the filling of each ladle and the average was recorded.

13. Wind pressure, as indicated in inches of water on a manometer, was recorded on every ladle and the average converted to oz. per sq. in. pressure. On completion of melting, the cupola blower was shut down and blowing time was recorded. Further details of the cupola operation are described in the paper previously mentioned.

Test Bars

14. For the purpose of complete chemical analysis, chill depth and iron strength determination, castings were poured from every ladle and the surplus iron was discharged in pig beds. Two chill castings, 3 x 1½-in. and 1½-in. square, 6-in. long, were poured from each ladle, except on heats of long duration when chills were poured from every other ladle. In addition to these, 2 x 1-in. test bars 26-in. long, molded in sets of four were cast at intervals as shown in accompanying tables.

15. These bar molds were dry sand with a facing of wet clay bonded coke blacking dried with the mold. They were cast vertically through a dry sand runner core equipped with a strainer and gated at the bottom.²

ANALYTICAL PROCEDURE

Analysis of Pipe Scrap for Charging

16. On each pipe to be broken for charging, silicon, evolution sulphur, and total carbon were determined. On a combination sample made up of representative drillings from all pipe to be charged in one heat, silicon, phosphorus, manganese, and total carbon were run in duplicates; and, in addition, sulphur, by both evolution and gravimetric methods, was determined.

Analysis of Iron Tapped

17. Each ladle tapped from the cupola was analyzed in duplicate for silicon and total carbon, and once for evolution sulphur and manganese.

18. Every set of test bars was analyzed for silicon and total carbon in duplicate; and the evolution and gravimetric sulphur, phosphorus and manganese were determined. In case of any undue variation from the expected results, thorough check analyses were made on another set of drillings on all samples.³

DISCUSSION OF RESULTS

19. In this discussion, and as shown on the accompanying charts, the different sizes of the coke are quoted as a definite figure for the sake of brevity. This figure was arrived at by adding

²For details of test bar equipment, see paper by Krynsky, A. L., and Saeger, Jr., C. M., "An Improved Method for Making Test Bars," A.F.A. Preprint 37-5, 1937, also JNL. OF RESEARCH, Bureau of Standards, vol. 16, no. 4, 1936.

³In all determination, A.S.T.M. Standard Methods were used.

Table 1*
RESULTS OBTAINED WITH ONE-INCH COKE

INDIVIDUAL PIPE ANALYSIS										Average Wind Pressure = 5.9 oz. Charge: Total No. = Seven 125 lb. charges				
Ladle No.	Silicon			Sulphur Evol.			S. Grav. Comb.		P. Comb.	Total Carbon			Stream Temp. ° F.	
	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.		Avg.	Max.	Min.		Avg.
1	1.36	1.22	1.28	0.058	0.045	0.051	0.083	0.59	0.938	0.51	3.34	3.16	3.24	3.23
2														
3														
4														
5														
6														
7														
Average														
Ladle No.	Analysis of Each Ladle			Mn. %	T.C. %	Average Test Bar Load lbs.	Average Defl. in.	Chill Depth		1½ in. Bar FG* in.	Stream Temp. ° F.			
	Si %	S %	Grav. %					3 in. Bar LW* in.	FG* in.					
1	1.37	.138	.39	3.61				.10	.06	.16	.06	2535		
2	1.30	.135	.44	3.58				.10	.09	.19	.13	2690		
3	1.29	.123	.46	3.44	.60	2950	.417	.31	.16	.38	.13	2715		
4	1.23	.115	.47	3.47	.60			.25	.13	.44	.22	2665		
5	1.34	.110	.44	3.44	.60	3020	.433	.44	.28	.31	.19	2645		
6	1.22	.103	.44	3.41	.60			.38	.25	.44	.19	2690		
7	1.23	.094	.44	3.47	.60			.47	.31	.31	.09	2655		
Average	1.28	.117	.44	3.49	.60			.32	.18	.32	.14	2652		

* Max. = Maximum found; Min. = Minimum found; Avg. = Average of samples; Comb. = Results obtained from combination sample of representative drillings.
LW—Last White.
FG—First Gray.

Table 2*
RESULTS ON SHORT HEAT 1 1/4-IN. COKE

Coke Size 1 1/4 x 1 in. Duration of Heat = 13 min.				Average Wind Pressure = 5.7 oz. Charge: Total No. = Seven 13 lb. charges			
INDIVIDUAL PIPE ANALYSIS				Total Carbon			
Ladle No.	Silicon		Sulphur Evol.	S. Grav. Comb.		Mn. Comb.	Comb.
	Max.	Avg.		Max.	Avg.		
1	1.42	1.37	1.37	0.055	0.052	0.53	3.24
2	1.39	1.23	1.39	0.055	0.052	0.53	3.24
3	1.29	1.21	1.39	0.055	0.052	0.53	3.24
4	1.25	1.21	1.39	0.055	0.052	0.53	3.24
5	1.28	1.21	1.39	0.055	0.052	0.53	3.24
6	1.24	1.13	1.34	0.055	0.052	0.53	3.24
7	1.26	1.06	1.37	0.055	0.052	0.53	3.24
Average	1.24	1.06	1.37	0.055	0.052	0.53	3.24
Analysis of Each Ladle				Average Test Bar			
Ladle No.	S		Mn.	T.C.		Average Load lbs.	Dest. in.
	Max.	Avg.		Max.	Avg.		
1	1.39	1.23	.30	3.59	3.27	3075	.450
2	1.29	1.21	.28	3.36	3.36	3030	.419
3	1.25	1.21	.42	3.40	3.37		
4	1.28	1.13	.49	3.36	3.37		
5	1.24	1.06	.48	3.36	3.36		
6	1.26	1.06	.46	3.36	3.36		
7	1.24	1.06	.42	3.39	3.39		
Average	1.24	1.06	.42	3.39	3.39		
Chill Depth				Stream Temp. ° F.			
Ladle No.	3 in. Bar		1 1/4 in. Bar	LW*		FG*	Stream Temp. ° F.
	Max.	Avg.		Max.	Avg.		
1	1.39	1.23	.19	.13	.19	.09	2580
2	1.29	1.21	.69	.50	.69	.44	2760
3	1.25	1.21	.81	.56	.75	.44	2760
4	1.28	1.13	.50	.31	.38	.18	2785
5	1.24	1.06	.69	.31	.56	.31	2785
6	1.26	1.06	.50	.31	.56	.31	2770
7	1.24	1.06	.69	.33	.56	.31	2770
Average	1.24	1.06	.58	.36	.53	.29	2760

* Max. = Maximum found; Min. = Minimum found; Avg. = Average of samples; Comb. = Results obtained from combination sample of representative drillings.
LW—Last White.
FG—First Gray

Table 3*
RESULTS OBTAINED ON LONG HEAT, 1 1/4-IN. COKE

INDIVIDUAL PIPE ANALYSIS										Average Wind Pressure = 5.5 oz. Charge: Total No. = Twenty 125 lb. charges				
Coke Size 1½ x 1 in. Duration of Heat = 105 min.			Sulphur Evol.				P.		Total Carbon		Stream Temp.			
Ladle No.	Si %	S Evol. %	Analysis of Each Ladle		Mn. %	T.C. %		Average Test Load lbs.	Defl. in.	3 in. Bar		1½ in. Bar		° F.
			Grav. %	P %		Max.	Min.			LW* in.	FG* in.	LW* in.	FG* in.	
1	1.53	1.13			.38	3.71				.04	.04	.04	.04	2660
2	1.50	.127			.47	3.53				.08	.05	.14	.10	2760
3	1.46	.133		.64	.46	3.49		2770	.424	.13	.08	.17	.11	2740
4	1.44	.130			.47	3.53				.20	.14	.16	.10	2730
5	1.44	.118		.66	.48	3.50		2550	.393	.27	.16	.24	.14	2720
6	1.44	.119			.49	3.46				.23	.12	.17	.09	2665
7	1.42	.114		.65	.51	3.53				.27	.15	.27	.13	2650
Average	1.47	.121		.65	.47	3.54								2704
8										.15	.07	.09	.05	2575
9	1.42	.086			.51	3.54				.19	.13	.27	.16	2580
10										.20	.10	.14	.07	2595
11										.15	.07	.18	.10	2590
12	1.39	.082			.51	3.51				.12	.05	.13	.06	2580
13	1.40	.085			.50	3.55				.23	.15	.17	.09	2580
14	1.39	.085			.50	3.51				.12	.05	.14	.07	2580
15	1.40	.089		.66	.51	3.51		2860	.450	.18	.11	.18	.11	2580
16	1.39	.078			.51	3.49				.11	.05	.09	.04	2640
average	1.43	.097		.65	.48	3.53				.20	.10	.15	.10	2640

* Max.—Maximum found; Min.—Minimum found; Avg.—Average of samples; Comb.—Results obtained from combination sample of representative drillings.

LW—Last White.

FG—First Gray.

the size of the large screen to that of the small one and dividing by two; for instance, the smallest coke used passed a $1\frac{1}{2}$ -in. screen and remained on the $\frac{1}{2}$ -in. and is designated as 1-in. coke.

One Inch Coke

20. The results obtained on the first heat are shown in Table 1. Only one heat was made using this extremely small coke ($1\frac{1}{2} \times \frac{1}{2}$ -in.) due to the difficulty of lighting off and to the fact that the iron melted cold throughout the heat. It was further decided after this heat to use standard size coke, 3-in. and up, to 12-in. above the tuyeres. Sulphur pick-up, although decreasing continually from the first ladle, was very high with this small coke.

21. Results of silicon determinations indicate that there was very little oxidation of the metalloids on this heat, as the average silicon analysis for the entire seven ladles was exactly that of the charge. The manganese loss was probably due entirely to its combination with sulphur. The carbon pick-up was rather high on this heat but this was partially due to the comparatively low carbon equivalent (Total Carbon + 0.3 Silicon + 0.3 Phosphorus) of the charge (3.80 per cent). The temperature of the iron was low throughout the heat.

One and One-Quarter Inch Coke

22. The next two heats, Tables 2 and 3, were made using coke that passed the $1\frac{1}{2}$ -in. and remained on a 1-in. screen. The second of these two heats was one of two long heats (20 charges) conducted to study the effect of length of heat on resulting analyses. The first seven ladles, however, were treated in the same manner as those from the other heats. The increase in temperature of these two heats as compared to the first was quite apparent. This increase amounted to approximately 100° F. The sulphur pick-up was higher on these two heats than on the one with the smaller coke. This was probably due to some extent to the higher temperatures.

23. The sulphur pick-up again decreased as the length of the heat increased but not so rapidly as on the first heat. Although the silicon loss was somewhat higher, it was only about half that when using $2\frac{1}{4}$ -in. coke. The manganese loss was rather high, approximately 23 per cent. As stated before, this was probably due to the high sulphur. The average carbon pick-up for these two heats was considerably lower than the first heat but may have

Table 4*
RESULTS OBTAINED ON 2 1/4-IN. COKE

Coke Size 3 x 1 1/4 in. Duration of Heat = 41 min.		INDIVIDUAL PIPE ANALYSIS										Average Wind Pressure = 4.8 oz. Charge: Total No. = Seven 125 lb. charges	
Ladle No.	Silicon		Sulphur Evol.		S. Grav.		P.		Mn.		Total Carbon		Comb.
	Max.	Min.	Max.	Min.	Avg.	Comb.	Comb.	Comb.	Comb.	Min.	Avg.	Comb.	
	1.49	1.34	0.064	0.048	0.057	0.055	0.061	0.08	0.57	3.45	3.35	3.41	3.39
Analysis of Each Ladle													
Ladle No.	Si		S		Grav.		T.C.		Mn.		Average Test Bar		Stream Temp. ° F.
	%	Evol.	%	%	%	%	%	%	in.	in.	in.	in.	
1	1.22	.110	.35	3.50					.69	.53	.59	.45	2640
2	1.34	.111	.40	3.53					.63	.42	.58	.40	2775
3	1.34	.117	.38	3.45	.130				.69	.38	.77	.52	2810
4	1.34	.109	.42	3.42	.120				.36	.22	.60	.34	2775
5	1.34	.108	.46	3.41					.57	.35	.58	.32	2805
6	1.31	.108	.49	3.40					.58	.38	.50	.30	2740
7	1.28	.112	.45	3.45	.125				.42	.23	.41	.23	2745
Average	1.31		.42	3.45					.56	.36	.58	.37	2755

* Max. = Maximum found; Min. = Minimum found; Avg. = Average of samples; Comb. = Results obtained from combination sample of representative drillings.
LW—Last White.
FG—First Gray.

Table 5*
RESULTS OBTAINED ON 2 1/4-IN. COKE

Coke Size 3 x 1 1/4 in. Duration of Heat = 45 min.										Average Wind Pressure = 4.2 oz. Charge: Total No. = Seven 125 lb. charges																	
INDIVIDUAL PIPE ANALYSIS																											
Max.		Min.		Avg.		Comb.		Silicium		Sulphur		Evol.		Avg.		Comb.		P.		Mn.		Total Carbon		Avg.		Comb.	
1.42		1.40		1.41		1.42				0.060		0.057		0.058		0.058		0.063		0.57		3.30		3.46		3.42	
Ladle No.		Si %		S Evol. %		Analysis of Each Ladle		P %		Mn. %		T.C. %		Average Test Bar Load lbs.		Defl. in.		3 in. Bar LW* in.		FG* in.		Chill Depth 1 1/4 in. Bar LW* in.		FG* in.		Stream Temp. ° F.	
1		1.19		.111						.33		3.47		2950				.53		.42		.53		.35		2560	
2		1.26		.106						.40		3.56		2950				.50		.35		.45		.28		2720	
3		1.30		.119		.137		.63		.42		3.52		2950		.443		.53		.29		.42		.30		2790	
4		1.32		.115						.47		3.52		2880				.50		.30		.28		.10		2760	
5		1.31		.111		.119		.64		.44		3.44		2880		.421		.45		.32		.45		.26		2740	
6		1.32		.112						.45		3.45						.45		.30		.62		.37		2745	
7		1.29		.118						.48		3.47						.57		.29		.30		.15		2760	
Average		1.28		.113		.128		.64		.43		3.49						.51		.33		.44		.26		2730	

* Max. = Maximum found; Min. = Minimum found; Avg. = Average of samples; Comb. = Results obtained from combination sample of representative drillings.

LW—Last White.
FG—First Gray.

* Max.—Maximum found; Min.—Minimum found; Avg.—Average of samples; Comb.—Results obtained from combination sample of representative drillings.
LW—Last White.
FG—First Gray.

Table 6*
RESULTS OBTAINED ON 4-IN. COKE

Coke Size 5 x 3 in. Duration of Heat = 32 min.				Average Wind Pressure = 4.2 oz. Charge: Total No. = Seven 125 lb. charges			
Ladle No.	Silicon		S Evol. %	Sulphur Evol.		Mn. Comb.	Comb.
	Max.	Min.		Max.	Avg.		
1	29	19	1.26	0.038	0.063	0.47	3.22
INDIVIDUAL PIPE ANALYSIS							
Ladle No.	Analysis of Each Ladle		Mn. %	T.C.		Average Test Bar	Stream Temp. ° F.
	Si %	S %		%	Load lbs.	Defl. in.	
1	.72	.077	.29	3.18			2450
2	1.05	.076	.37	3.24			2610
3	1.03	.081	.35	3.24	2990	.302	2730
4	1.14	.075	.37	3.27			2765
5	1.12	.072	.41	3.28	3305	.418	2740
6	1.11	.069	.45	3.28			2840
7	1.09	.068	.41	3.33			2800
Average	1.04	.074	.38	3.26			2848

* Max. = Maximum found; Min. = Minimum found; Avg. = Average of samples; Comb. = Results obtained from combination sample of representative drillings.
LW—Last White.
FG—First Gray.

Table 7*
RESULTS OBTAINED ON SECOND SHORT HEAT

Coke Size 5 x 3 in. Duration of Heat = 33 min.				Average Wind Pressure = 3.3 oz. Charge: Total No. = Seven 123 lb. charges			
Silicon				INDIVIDUAL PIPE ANALYSIS			
Max.	Min.	Avg.	Comb.	Max.	Min.	Avg.	Comb.
1.41	1.24	1.30	1.29	Max.	Min.	Avg.	Comb.
				Sulphur Evol.			
				Max.	Min.	Avg.	Comb.
				0.055	0.050	0.052	0.055
				S. Gray.			
				Max.	Min.	Avg.	Comb.
				0.055	0.050	0.052	0.055
				P.			
				Max.	Min.	Avg.	Comb.
				0.055	0.050	0.052	0.055
				Total Carbon			
				Max.	Min.	Avg.	Comb.
				3.23	3.22	3.24	3.23
Analysis of Each Ladle				Chill Depth			
Si	S	Evolution	Grav.	3 in. Bar	1 1/4 in. Bar	Stream	Temp.
%	%	%	%	LW*	LW*	Temp.	° F.
1	2	3	4	5	6	7	
.91	.089	.080	.106	3.00	1.50	1.50	2845
1.12	.080	.080	.106	1.50	.81	1.50	.87
1.13	.082	.082	.106	2.00	.87	1.50	.75
1.18	.086	.086	.106	3.00	.94	1.50	1.00
1.11	.080	.080	.106	1.33	.56	1.50	.81
1.15	.078	.078	.106	1.25	.75	1.50	.94
1.17	.080	.080	.106	1.33	.87	1.50	.81
1.11	.072	.072	.106	1.83	.84	1.50	.95
Average	1.11	.072	.106	1.83	.84	1.50	.95

* Max. = Maximum found; Min. = Minimum found; Avg. = Average of samples; Comb. = Results obtained from combination sample of representative drillings.
LW—Last White.
FG—First Gray.

Table 9*
RESULTS OBTAINED WITH LARGE COKE IN BASIN

Coke Size: To 8 in. above tuyeres 1½ x 1 in. To 60 in. above tuyeres 5 x 3 in.															Duration of Heat = 40 min. Average Wind Pressure = 2.9 oz. Charge: Total No. = Seven 125 lb. charges																								
INDIVIDUAL PIPE ANALYSIS															Total Carbon																								
Silicon					Sulphur Evol.					S. Grav.					P.					Mn.					Comb.														
Max.		Min.		Avg.		Max.		Min.		Avg.		Comb.		Max.		Min.		Avg.		Comb.		Max.		Min.		Avg.		Comb.											
1.48		1.44		1.46		0.055		0.045		0.049		0.048		0.053		0.63		0.49		3.55		3.44		3.50		3.46													
Analysis of Each Ladle															Chill Depth																								
S					P					Mn.					T.C.					Average Test Bar Load lbs.					3 in. Bar					1½ in. Bar					Stream Temp. ° F.				
Ladle No.		Si %		S Evol. %		S Grav. %		P %		Mn. %		T.C. %		Load lbs.		Defl. in.		LW* in.		FG* in.		LW* in.		FG* in.		Temp. ° F.													
1		1.21		.111						.32		3.49						.52		.39		.54		.39		2456													
2		1.34		.106						.36		3.52						.50		.27		.49		.28		2641													
3		1.36		.102		.123		.63		.39		3.56		3046		.452		.70		.33		.52		.30		2750													
4		1.37		.104						.40		3.57						.55		.28		.49		.26		2750													
5		1.39		.096		.107		.62		.40		3.60		2788		.423		.50		.30		.50		.33		2755													
6		1.39		.092						.40		3.63						.22		.12		.24		.11		2728													
Average		1.34		.101		.115		.63		.38		3.56						.50		.29		.48		.28															

* Max.—Maximum found; Min.—Minimum found; Avg.—Average of samples; Comb.—Results obtained from combination sample of representative drillings.

LW—Last White.

FG—First Gray.

Table 10*
RESULTS OBTAINED WITH LARGE COKE IN BASIN

Coke Size:		To 12 in. above tuyeres $1\frac{1}{4} \times 1$ in.		To 50 in. above tuyeres 5×3 in.		INDIVIDUAL PIPE ANALYSIS				S. Grav.		P.		Mn.		Total Carbon		Stream Temp. °F.
		Max.	Min.	Avg.	Comb.	Max.	Min.	Avg.	Comb.	Sulphur	Evap.	Comb.	Comb.	Max.	Min.	Avg.	Comb.	
		1.49	1.43	1.45	1.49	0.061	0.050	0.056	0.055	0.063	0.067	0.67	0.48	3.48	3.43	3.45	3.47	
Ladle No.	Si %	Analysis of Each Ladle		S Evap. %	Grav. %	F %	Mn. %	T.C. %		Average Test Bar Load lbs.	Defl. in.	3 in. Bar LW* in.		Chill Depth LW ² in.		1½ in. Bar FG* in.		
		Max.	Min.					Max.	Min.			Max.	Min.	Max.	Min.	Max.	Min.	
1	1.47			.108			.35	3.60				.22	.11	.20	.11	.11	.11	2543
2	1.45			.103			.37	3.57				.36	.18	.32	.16	.16	.16	2628
3	1.43			.115	.127	.64	.35	3.49	2590	.303		.19	.09	.15	.08	.08	.08	2712
4	1.42			.103			.36	3.56				.30	.17	.37	.19	.19	.19	2715
5	1.39			.106	.121	.64	.41	3.55	2750	.366		.38	.19	.37	.20	.20	.20	2686
6	1.37			.099			.40	3.53				.31	.17	.27	.15	.15	.15	2547
Average	1.42			.106	.124	.64	.37	3.55				.29	.15	.28	.15	.15	.15	

* Max.—Maximum found; Min.—Minimum found; Avg.—Average of samples; Comb.—Results obtained from combination sample of representative drillings.

LW—Last White.

FG—First Gray.

been partly due to the higher carbon equivalent of the charges in the last heat.

Two and One-Quarter Inch Coke

24. The heats were made on coke that passed a 3-in. screen and remained on the $1\frac{1}{2}$ -in. or $2\frac{1}{4}$ -in. coke (Tables 4 and 5). The sulfur pick-up was noticeably lower with this larger coke, although it did not diminish on each succeeding ladle as in previous heats. The silicon loss increased to approximately 9 per cent, but this size coke gave the best results from an operation standpoint and was used as the basis for comparison with other heats. Since the manganese loss increased slightly, about 25 per cent, with the lower sulfur content, there must have been some oxidation in the stack. The carbon pick-up continued to decrease with this increase in coke size.

Four Inch Coke

25. Three heats were made using 4-in. coke (Tables 6, 7 and 8). One of these heats was 20 charges in. length to use as a companion heat to the one with small coke. The sulfur pick-up continued to decrease as the coke size was increased and, as with the $3 \times 1\frac{1}{2}$ -in. coke, did not diminish as the age of the heat increased. The increase in silicon loss was considerable with this coke, averaging 14.5 per cent which is rather high when compared to the 9 per cent loss with $2\frac{1}{4}$ -in. coke.

26. The manganese loss was very high, averaging 27 per cent. This is somewhat higher than with $2\frac{1}{4}$ -in. coke and, coupled with the fact that the sulfur was much lower, leads us to believe that there was excessive oxidation in the stack with this large coke.

27. As can be seen from the tables, the carbon analyses varied from a pick-up of 13 points to a loss of 13 points. This was partly due to the 0.34 per cent difference in carbon equivalent of the charge. However, the average of the three heats shows a definite decrease in the carbon pick-up with this coke. The average temperature of the iron from this set of heats decreased when compared to the two series with $2\frac{1}{4}$ -in. coke.

Large Coke in Basin

28. To check the effect of the large coke placed in the basin of the cupola on all these tests, two heats were made with 8 and

12 in. of 1 $\frac{1}{4}$ -in. coke in the basin and using 4-in. coke for the balance of the bed and for the succeeding charges. The detailed results of these two heats are shown on Tables 9 and 10.

29. Although there was no appreciable difference in the amount of sulfur pick-up on these two heats, considered individually, their average was considerably higher than that with the larger coke in the basin. The 6.5 per cent silicon loss of these two heats is a sharp decrease from the 15 per cent of the companion heats with large coke in the basin. The manganese loss of 23 per cent was slightly lower in spite of the higher sulfur; the average carbon pick-up was somewhat higher.

Average Results

30. Figs. 1, 2, 3, 4, and 5 are graphical representations of the average results for each ladle of all the heats for the different sizes of coke. The results of the last two heats are shown with a dotted line. These charts disclose several interesting facts. Fig. 1 shows clearly the extremely high decrease in sulfur pick-up, after the first two ladles, with the small coke. The dotted line curve for the last two heats is interesting due to the fact that it is so much higher than its companion curve with 4-in. coke.

31. The most interesting feature of Fig. 2 is the low silicon loss by using small coke to start the bed. The decrease in the loss of this element on the first ladle is especially striking.

32. The manganese loss curves in Fig. 3 in most all instances show a decrease from the first ladle and do not flatten until the fifth or sixth ladle. The manganese loss on the heats with small coke in the basin was much less, especially on the first part of the heat, than on the other heats with 4-in. coke.

33. The carbon pick-up curves of Fig. 4 show the relative change in the amount of pick-up of this element by changing the size of coke. The curve for the two heats with small coke in the basin indicates the slightly higher pick-up when compared to the other curve for 4-in. coke.

34. In Fig. 5, the average temperature of each ladle was plotted for the different sizes of coke. One of the features of this chart is the low spout temperatures throughout the heat on the extremely small coke. This chart also shows the superiority of the 2 $\frac{1}{4}$ -in. coke for high temperatures.

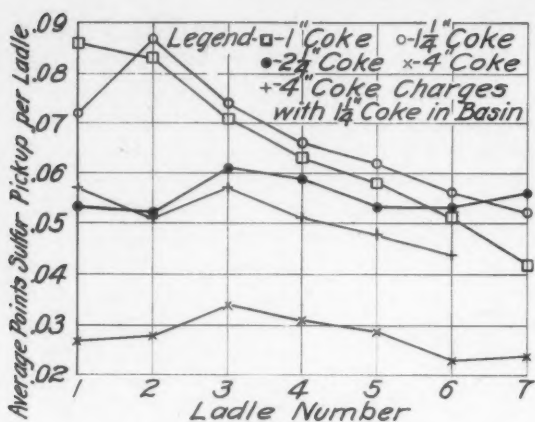


FIG. 1—SULPHUR VARIATIONS IN HEATS

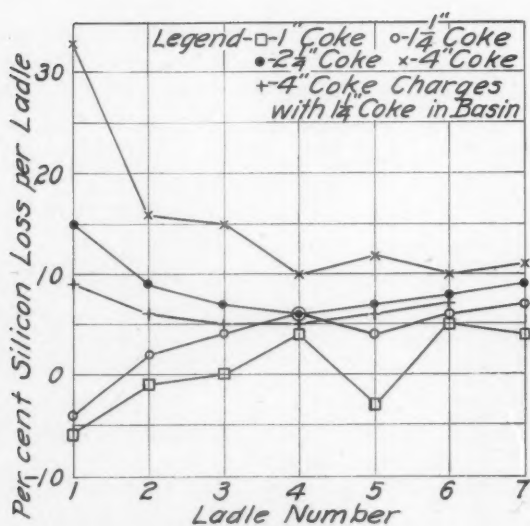


FIG. 2—SILICON VARIATIONS IN HEATS

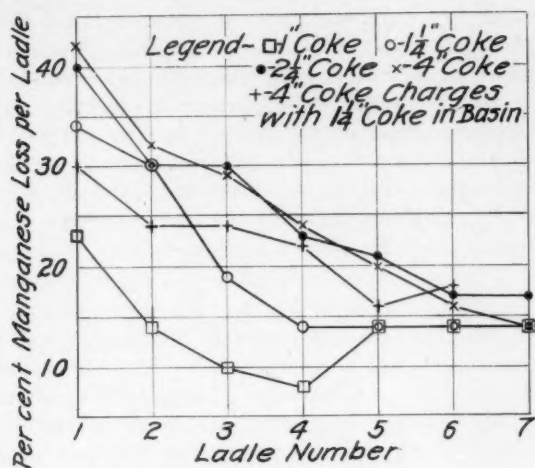


FIG. 3—MANGANESE VARIATIONS IN HEATS

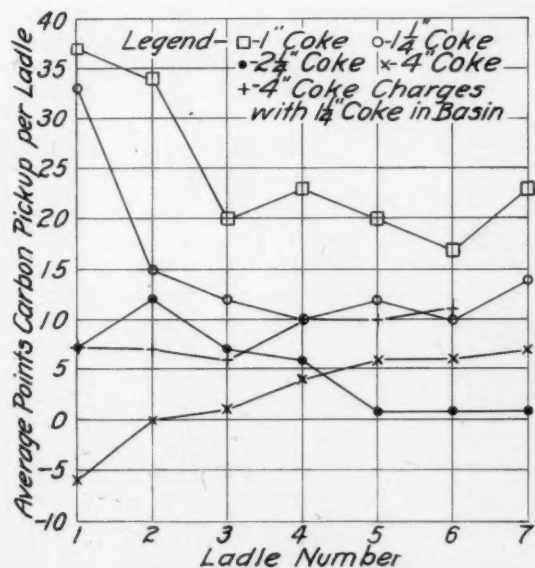


FIG. 4—CARBON VARIATIONS IN HEATS

Summary Chart

35. Fig. 6 might be termed a summary chart, as it gives the grand average of the changes in analyses with each succeeding change in coke size. This chart discloses the fact that the sulfur pick-up was approximately the same on the first two sizes of small coke and then decreased rapidly in approximately direct proportion to the increase in coke size. Another interesting fact, seen on this chart, is the similarity of the two lines constructed from the different methods for determining sulfur. Although the gravimetric determination is 9 points, on the average, higher than the evolution method, the two determinations form practically parallel lines. The enlarged points on this part of the chart are the average for the two heats with small coke in the basin. They show clearly the increase in sulfur pick-up on these tests.

36. The carbon pick-up curve, after a tremendous drop from the smallest coke to the next larger size, flattened rapidly, although continuing to decrease, with further increases in coke size. Due to the fact that the average carbon equivalent of the charges for different sizes of coke varied 32 points, this curve is not wholly reliable. This difference would be reflected more in the extremely large drop from the one to the $1\frac{1}{4}$ -in. coke than for the balance of the curve. The reason for this is that the variation in carbon

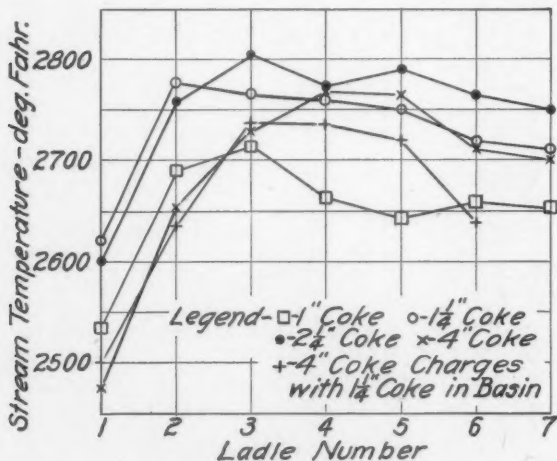


FIG. 5—VARIATIONS IN TEMPERATURE OF METAL WITH DIFFERENT COKE SIZES IN CHARGE

equivalent for the average of the different series, excluding the first heat, was only 15 points. The increase in carbon pick-up for the heats with small coke in the basin is indicated by the enlarged open circle. This increase was in spite of the fact that the carbon equivalent of the charge for these heats was considerably higher than that for the other 4-in. coke heats.

37. A glance at the silicon loss curve shows it as practically the reverse of the carbon pick-up curve. The loss of silicon increases rapidly with the first increase of coke size and the curve then flattens out with the loss increasing in practically a straight line with each additional increase in coke size. The extreme decrease in silicon loss of the last two heats is shown clearly by the large solid circle.

38. The curve for the manganese loss was almost parallel to the silicon loss curve to the 2 $\frac{1}{4}$ -in. coke but no further loss of this element was seen in increasing the coke size to 4-in.

Melting Rate

39. Fig. 7 shows the melting rate for the different coke sizes, separating the two long heats from the short ones. The temperature curve is the next most interesting and this curve shows that the 2 $\frac{1}{4}$ -in. coke gave the highest temperature average. This average was 25° F. higher than heats with the 1 $\frac{1}{4}$ -in. coke and 60° F. higher than the 4-in. coke.

40. The wind pressure curve shows that the pressure decreased as the coke size increased.

Change in Elements in Heats of Long Duration

41. Fig. 8 gives four sets of curves for the change in the different elements on heats of comparatively long duration when using the small (1 $\frac{1}{4}$ -in.) coke and the large (4-in.) coke.

42. *Carbon:* The carbon curve for the 4-in. coke shows a loss of carbon throughout the heat. This is the only heat of the entire set in which there was a loss of carbon. This carbon curve follows very closely the temperature curve shown on Fig. 9. The carbon loss diminished rapidly from the first to the fourth ladle and then approaches a straight line as does the temperature curve. The carbon pick-up from the second ladle throughout the heat on the 1 $\frac{1}{4}$ -in. coke was within 5 points of a straight line after an enormous pick-up on the first ladle.

43. *Sulphur:* The sulfur pick-up curves show that after

the tenth ladle, the amount of sulfur absorbed was approximately the same on both the large and small coke. The fact that the sulfur pick-up increased from a comparatively low amount on the first ladle, for three or four ladles may be explained by the fact that standard foundry coke was used to 12-in. above the tuyeres. The curves for the silicon loss with the 4-in. coke, after an ex-

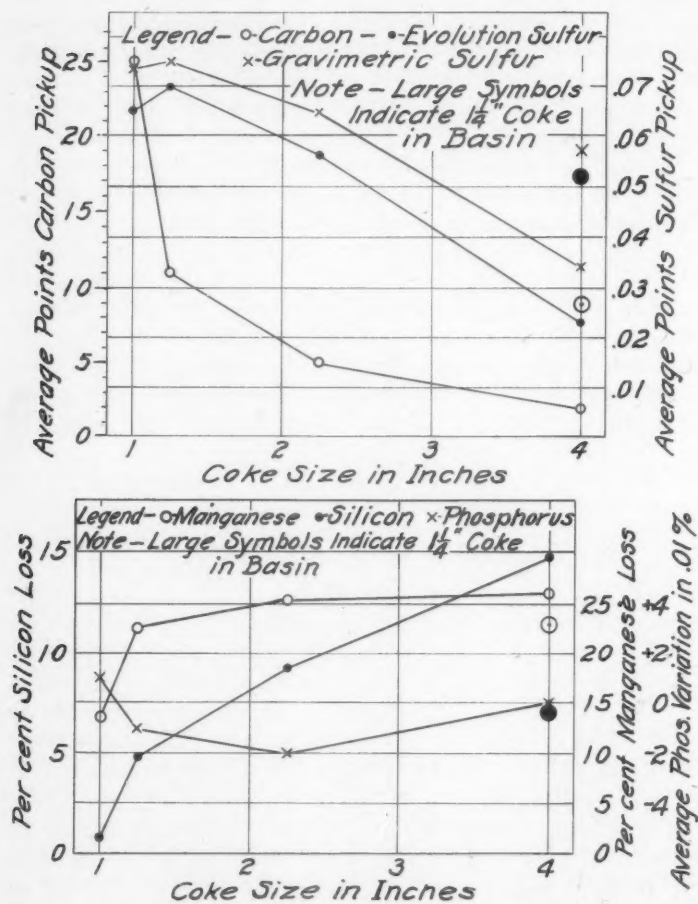


FIG. 6—AVERAGE CHANGES IN ANALYSES WITH EACH SUCCEEDING CHANGE IN COKE SIZE

tremely high loss of 40 points, decreased sharply to the sixth ladle and then ran along a straight line. This curve for the small coke, beginning with no loss on the second ladle, increased through the sixth ladle and then coincided with the curve for 4-in. coke for the remainder of the heat. This is an interesting fact and leads to the supposition that the larger coke becomes packed or more compact, thus closing up the voids so much so that the blast cannot go through with enough velocity to impinge on and oxidize the metal.

44. *Manganese*: The manganese loss curves approximately coincide throughout the heat. However, it should be pointed out that the extremely high loss of the first few ladles of both heats was probably due to entirely different causes. The high loss on the small coke was probably due entirely to the high sulfur as

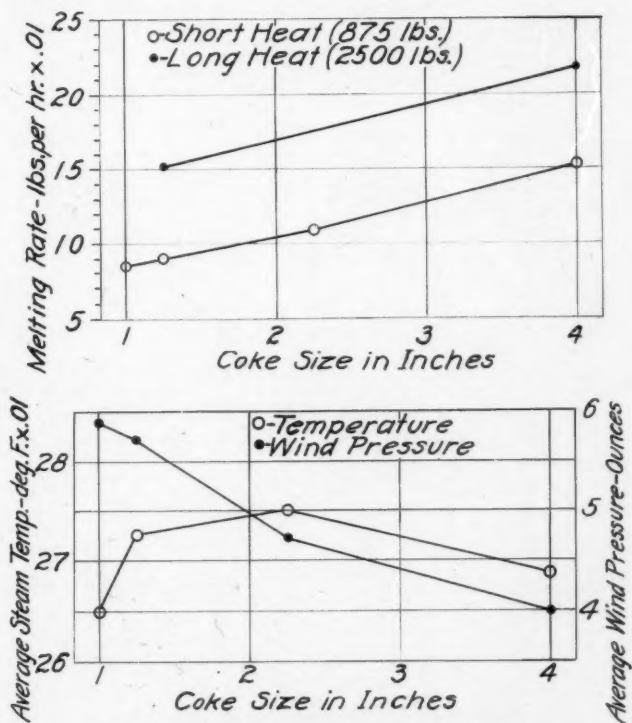


FIG. 7—MELTING RATE FOR DIFFERENT COKE SIZES

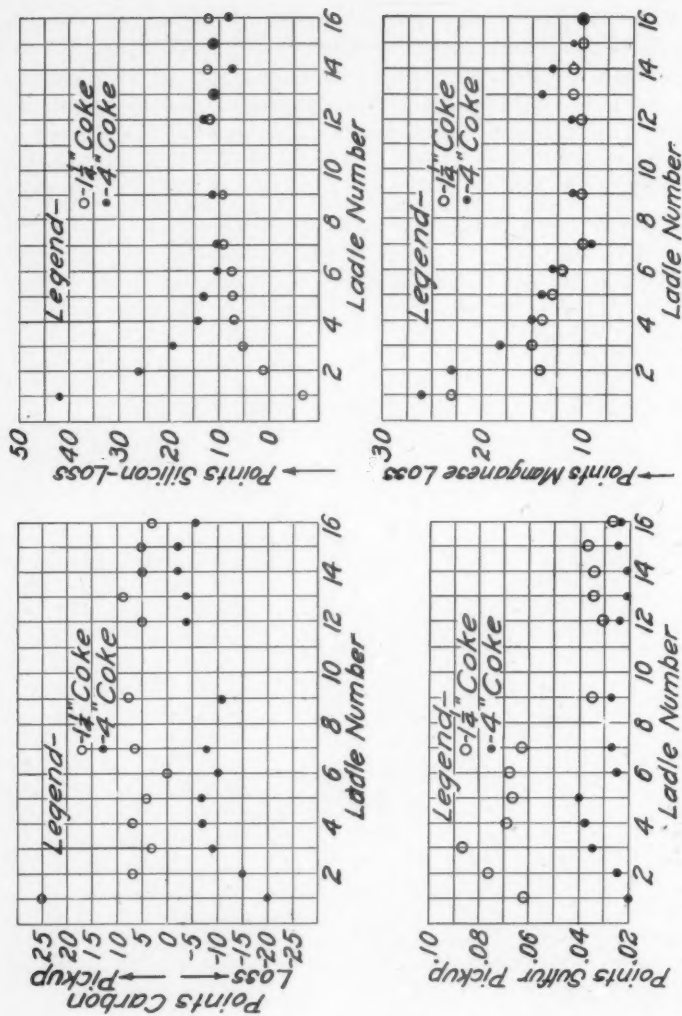


FIG. 8—VARIATIONS IN DIFFERENT ELEMENTS IN HEATS OF LONG DURATION WHEN USING VARIOUS SIZED COKE

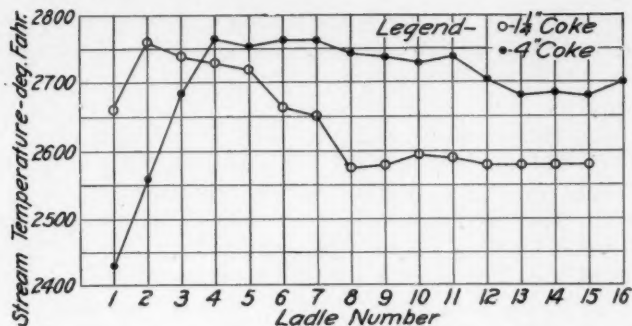


FIG. 9—VARIATIONS IN TEMPERATURE IN HEATS OF LONG DURATION WITH VARIOUS SIZED COKE

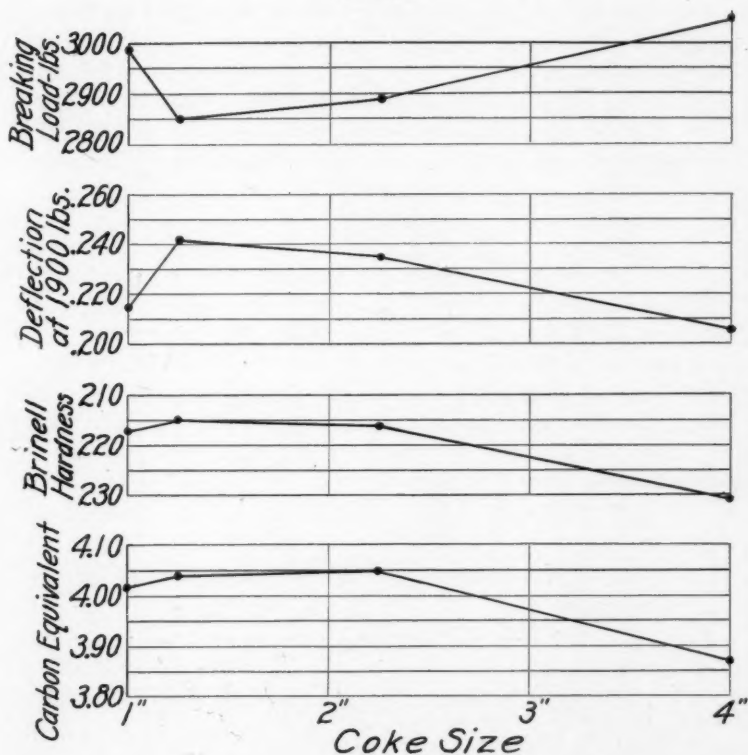


FIG. 10—VARIATIONS IN PHYSICAL PROPERTIES OF IRONS PRODUCED USING VARIOUS SIZE COKE IN THE CHARGE

explained before. This loss at the beginning of the heat with 4-in. coke was probably due to oxidation to a certain extent, as confirmed by the fact that there was a high loss of silicon also during this period.

45. *Temperature:* Fig. 9 gives the temperature curves for the two heats by ladle number. No explanation has been found for the temperature drop after the first few ladles.

46. *Physical Properties:* Fig. 10 shows the average carbon equivalent, breaking load, deflection at 1900 lb. load, and Brinell hardness curves for the 2 x 1-in. test bars for different coke sizes. These test bars were broken on 24-in. supports, centrally loaded, and the maximum variation in the average breaking loads was less than 200 lb. This is considered a rather small variation in view of the fact that there are so many variables that affect the breaking loads of test bars. The breaking load and deflection curves follow the carbon equivalent curve closely enough to lead to the supposition that the iron was not otherwise affected by changing coke size. The Brinell hardness curve was plotted on a descending scale to show its similarity to the carbon equivalent curve.

CONCLUSIONS

47. There are a number of conclusions, that seem logical to the investigators, to be drawn from these experiments. These conclusions are applicable only on a 21-in. diameter cupola, constructed and operated as in these tests. However, they should indicate the general trend of results for any cupola when changing from one coke size to another.

48. The following conclusions would hold true for heats of comparatively short duration only:

1. The sulfur pick-up increases with each decrease in coke size.
2. The silicon loss decreases with each decrease in coke size.
3. The amount of carbon pick-up increases with each decrease in coke size.
4. The manganese loss decreases with each decrease in coke size. This may be offset to a certain degree by the higher sulfur when using small coke.
5. The spout temperatures reach a maximum with some

intermediate coke size probably depending on the size of the cupola and the blast pressure or velocity.

6. Melting speed is reduced when the coke size is decreased.

7. The wind pressure naturally increases with each decrease in coke size.

49. The most outstanding conclusion to be drawn for heats of longer duration is that after the first eight to ten ladles, the changes in the elements are practically unaffected by changes in coke size. This is particularly true of the silicon and manganese. The sulfur and carbon pick-ups increase slightly when changing from the largest to the smallest size coke.

50. Other information obtained from the longer heats is as follows:

1. Spout temperatures change with changing coke sizes.
2. Melting speed is decreased by decreasing coke size.

51. These experiments further indicate that there is an optimum size for the coke to be used in a given cupola. When this size is found, maximum temperatures will be reached and better and more even cupola operation obtained. The best size for the cupola used in these experiments is 2 to 3-in.

ACKNOWLEDGMENTS

52. The authors wish to thank all those who helped in making these tests, particularly R. H. Elder* and Roy E. Deas* for their work in making the chemical determinations.

DISCUSSION

Presiding: H. BORNSTEIN, Vice-President, A.F.A. and Director of Laboratories, Deere & Co., Moline, Ill.

R. A. CLARK¹: (*Submitted as Written Discussion*). This paper was particularly interesting to me for I have been convinced for some time that a wide variation in coke size can be quite as potent a variable in cupola operation as the more commonly recognized variation on coke structure and combustibility. In this paper, however, the authors draw certain conclusions as to the effect of coke size which it seems to me are not justified by the data presented. From the description of the furnace

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¹ Metallurgist, Lakey Foundry & Machine Co., Muskegon, Michigan.

given in their paper of last year, I am assuming that the cupola was blown by a simple fan blower without any means of knowing the blast volume. As will be noted, the blast pressure or stack pressure caused by resistance of the stock to passage of the blast increases as the coke size is decreased and presumably the blast volume will be lower with the high resistance caused by small coke than when operating the stack with larger coke and a lower back pressure.

That such is the case would be indicated by Fig. 7 showing that the melting rate and wind pressure are almost inversely proportional and that on short heats, as the coke size increased, pressure decreased, and melting rate increased as follows:

<i>Coke Size</i> Inches	<i>Pressure</i> Ounces	<i>Melting Rate</i> Lb. per Hour
1	5.9	850
1¼	5.7	900
2¼	4.7	1100
4	4	1550

It does not seem logical to me that melting rate would be almost doubled by a change in coke size alone and I believe that the conclusions as to the optimum coke size for this cupola might have been changed materially had the furnace been equipped with an accurate blast volume control such as is used in most of the newer commercial cupola installations.

JAS. T. MACKENZIE: Mr. Clark's remarks are especially well taken, but it is clearly stated in the paper that the results are on the small cupola and blown by a certain type of fan blower, and inasmuch as many people are using the fan type, the results would be comparable. However, if the same volume is shoved into the cupola in spite of the pressure, as could be done with a positive pressure blower, the melting rate would increase with the low sizes of coke due to the increase of carbon monoxide formed.

In regard to Mr. Clark's last sentence, however, I think he is much more optimistic about accurate blast volume control than I am since none of them can regulate beyond the capacity of the blower. With the General Electric control that we have, for instance, it is only necessary to get a pressure of 25 ounces in the cupola when the blower fails absolutely to push in any more wind. This is, of course, on a large stack. Had we had a 5-ounce controller on this test installation, it would not have done any good for sizes smaller than 2¼ in.; but it would have materially increased the rate on the 2¼ in. and 4 in., especially the 4 in.

ROBT. H. WATSON²: I am very glad to have been here to hear this paper for Dr. MacKenzie a number of years ago had me made a member of the committee in the American Society for Testing Materials where I believe the beginning of this work was done.

I would like to state briefly the effect of size of coke in blast furnace operation in two different operations with which I have been connected.

² Metallurgist, The Hanna Furnace Corp., Ecorse, Detroit, Mich.

In one case our coke came to us unsized, that is, all put through a 3-in. screen, and the very small coke was taken out at the blast furnace by a $\frac{1}{2}$ -in. screen. We were able, by paying this coke company fifty cents more a ton, to have this screened through a $2\frac{1}{2}$ -in. screen and over a $1\frac{1}{2}$ -in. screen.

On these two blast furnaces, the amount of coke of the original size was about 2300 lbs. per ton of iron reduced. On changing over, with the same stoves and the same blast temperature but with sizing the coke, we were able to increase the output of the furnace 10 per cent, and our temperatures, which had hitherto been about 2700° F. at the spout, indicated by a good contact pyrometer as well as checking with optical pyrometers, we consistently ran 2800° F. in temperature.

At another plant that I put into operation shortly after that, where the furnaces were considerably larger, being up to 20 ft. in hearth diameter, we sized the coke under practically the same conditions. In these furnaces we made 4.5 per cent silicon iron with 1400° F. blast temperature with a coal mixture containing 20 per cent low volatile and 80 per cent high volatile coal-coke mixture using 2088 lbs. of coke per ton of metal.

As to the coke size, in using cupolas, there is one company whose practice I am acquainted with, that sizes 4 in. coke, 5 in. coke and a coke that they call 7 in. x 3 in. In each of these cases, both in the manufacture of castings for automobiles and in general jobbing shops, it has been my good fortune to see the change from the various sizes of coke put into a standard sizing of coke. In each case the iron has been increased in temperature and the output in a number of cases has been greatly increased with the same apparatus that they had on hand.

It may be of interest to know that the porosity of the coke has little or nothing to do with the rate of burning, this rate of burning being entirely governed by the geological formations from which the coals are taken. The sizing of the coke for the various sized cupolas, among other things permits, even with lack of sufficient blast, a melting zone that is down where it should be, therefore producing constant carbon analysis. Let me point out that large coke used in a small cupola would invariably produce high penetration, thus causing the charge to melt too high in the cupola creating an oxidized atmosphere. May I also point out that in connection with the sizing of coke, all users of foundry coke would be benefited by combustibility tests.

I think that this sizing of the coke and this work that Dr. MacKenzie has begun is of equal importance with the introduction of the hot blast in the manufacture of pig iron.

DR. MACKENZIE: There is one point that probably should be borne in mind that I do not believe was stated in the paper and that is, this is not what you would ordinarily call a small coke. It was big lumps of coke crushed and put through these screens. We will have to make a note of that because it was not just the little coke that was screened out of the car.

MEMBER: Dr. MacKenzie, in doing this work, do you believe that it is possible to arrive at some mathematical ratio whereby an individual foundryman will not have to go through the entire range of experiments

for their given cupola, or do you see any hope for a formula some day that will guide them on their way?

DR. MACKENZIE: I am afraid that would depend on the blast pressure, the kind of coke available, and the size—three variables that would be very hard to get into a formula.

H. E. BAUGHMAN³: We are making more sized coke than we did say five or six years ago. During the depression we found quite a few of our customers lined their cupolas to smaller diameters, say 30 in. to 42 in. This was done in order to take off smaller heats. With the smaller cupolas, these foundries wanted a smaller coke than our regular size. In order to meet this demand, we installed a coke crusher and screening apparatus, producing such sizes as 2¼ in. x 5 in., 3 in. x 6 in. and 4 in. x 6 in.; in conjunction with these crushed sizes, we make a small average size coke. The results from this sized coke are apparent as even today these same foundries are demanding some of these various sizes. I wish to mention, however, that making sized coke has resulted in added expense to us, in that there is a lesser yield of coke, due to degradation in crushing.

MEMBER: Is there not less tendency for carbon pick-up when using a harder structure coke than there is in the use of a soft structure coke? We find sometimes we have a hard coke and I have noticed upon analysis that I have had lower carbon. I would get soft coke occasionally, with a dark, soft structure, honeycombed, and I have paid particular attention, and the carbon has been higher in that soft coke. I am using small coke now; it was suggested we use a small coke to see if we would get better results, which we have done. I have ordered, as a special foundry coke, 3 in. x 6 in. and I have found I have gotten much better results, hotter iron and faster melting with this smaller coke than I did with the large coke. I am using what they call a No. 4 cupola, lined down to 42 inches inside.

DR. MACKENZIE: I had a paper before this association in 1930 on about eight or nine cokes, that showed the greater carbon absorption with the soft cokes. The maximum carbon absorption that we have found would be, for instance, with a pitch coke. With an old 17 per cent ash beehive coke you can tap out with 1½ per cent carbon. You cannot get very much temperature with it. In between we find the ash content appears to be trying to dominate but the other characteristics of the coke overcome the ash content, so that you will find a 7 per cent ash coke with a very good structure will give lower carbon absorption than a 9 per cent ash coke, with a poorer structure. But, generally speaking, I doubt if you could overcome, say 4 per cent ash, by any change in the structure of the coke.

P. T. BANCROFT⁴: This paper is very interesting but we foundrymen have to take the coke out of a car; it is not passed over a screen and put into a cupola like this one. Now, I just want to emphasize the importance of the uniformity of size of the coke. Regardless of how you charge the coke, whether by weight or by measure, fine cokes will not raise the coke

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⁴ Moline, Ill.

bed as high as the coarser cokes will. Consequently, if you have a large pile of coke, the big lumps will roll down and you will get the coarser cokes up and eventually you come to your fine cokes. You immediately have dropped your bed and you get a drop in carbon. I have heard a lot of foundrymen say, "I got into trouble and I got out of it, and I do not know how I got in and I do not know how I got out of it". Now, I am just giving that as a hint, that a lot of our troubles in the foundry are probably due to the variation in coke size.

MEMBER: Dr. MacKenzie made reference to the size of coke not being square but that it could be elongated. He was, I believe, speaking of screening over a cross-parallel screen or a straight parallel screen. If that coke was $2\frac{1}{2}$ in. square on the end and ran up to a length of 6 inches, would it be included in such coke size as Dr. MacKenzie used?

DR. MACKENZIE: All the screens we used were either rectangular or round. I don't imagine the length would have very much to do with it. It would be very largely a matter of cross section.

MEMBER: Mr. Bowers, do you think it is possible, after about the seventh charge, to change over from the best coke to most any coke, change to maybe a smaller coke or a larger coke? You show that your losses in silicon and manganese, etc., get constant after about the seventh charge with a small or a large coke. Then if you started out with the best coke for the particular cupola, could you use just any old coke after the seventh or eighth charge and still run a fairly good heat?

MR. BOWERS: That is a rather difficult question. We didn't try that. Offhand, I think, the main thing that does happen after the seventh or eighth or tenth ladle is the change in temperature, so that when you find the optimum size of coke to use, if you want to maintain that high temperature, you must keep using that size coke. But as to the change in analysis, according to these tests, it doesn't look like a change in coke size after the tenth ladle would affect the analysis very much, but it certainly would affect the temperature.

MEMBER: Relative to that curve that you showed, where the right size coke went up to maximum temperature and stayed there and the large size coke sank down to the temperature after about one-third of the heat, I believe you said you had no information as to why that large coke rose to a maximum and then fell. Do you have any theories that might give us a hint as to why that should be? Might it be the fact that it was the wrong size cupola?

DR. MACKENZIE: I don't know. Only two heats were run on each of those and there is a strong tendency to bridge with that big coke, so that some of these erratic results with the large coke on this cupola might be due to some bridging. It would certainly drop the bed and it might do it periodically, every 15 or 20 minutes.

I was at a blast furnace meeting not so long ago and I found that, in running these lean Southern ores, they have to take the blast off the furnace about every half hour or so, just shut it down. If they don't the

furnace will bridge up altogether. So I am afraid some of the erratic results may be due to that.

ROBT. H. WATSON: In regard to the question about the different sizes of coke, in the part of the country where I come from there has been difficulty in securing coke for the last four or five weeks and in several cases I have seen two or three different kinds of coke used in the same heat. In an automobile factory they were fortunate enough to have one very good bee-hive coke and they ran there very successfully. They broke the bee-hive coke up into pieces about 4 inches long and put their bed in with that. The bed was 50 inches. The iron was nice and hot but the carbons varied. The first ran 3.20 per cent C., the next, 3.60, then 3.06, and then 3.35. That was when the other coke came into the picture.

Sand Control in Relation to Steel Foundry Production

BY CHARLES FURST,* MILWAUKEE, WIS.

1. No foundry has ever operated without some type of sand supervision. In the past, and in a good many shops even today, the department foreman, alone, carries the full responsibility for what he may consider the proper preparation of the sand used in his department. However, along with the demand for better castings, there has come the realization that the foreman must be given some assistance in the form of accurate test figures and records in order that correct sand conditions can be determined and maintained. By taking full advantage of these test results, guess work is eliminated, the reasons for failures due to sand become better understood and the necessity for a particular sand mixture to meet the requirements of this or that job becomes obvious. As mold requirements become better known, standard mixtures can be set up to reasonably meet the demands in both molding and core sand for any class of work.

2. The purpose of this paper is to attempt to show in a practical way, the value and need of accurate sand control in producing the best possible castings with the materials and equipment available, at the same time keeping an eye on cleaning and material costs.

3. The following discussion is a more-or-less general description of the writer's experiences in preparing sand mixtures for open hearth steel castings, ranging from bench work to ninety-five ton jobs. There is no intent to convey the impression that test figures quoted will prove equally satisfactory in other foundries where conditions and practices may be different. However, the principles governing these results can be applied to established proper standards in practically any foundry.

4. Laboratory test figures are not, in themselves, sufficient to insure satisfactory physical properties in a molding or core sand. It is necessary that the prepared sand be workable, which means that it must have the right feel to it and that it must retain its moisture sufficiently so as to cause no difficulty in finishing.

* The Falk Corporation.

NOTE: Presented before Steel Division Session of 41st Annual Convention, Milwaukee, Wis., May 6, 1937.

WORKING PROPERTIES

5. For light green sand work, such as bench and squeezer work, a fine round grained sand with an A.F.A. grain fineness of 53 produces excellent results when mixed to give the following properties:

Moisture (Per Cent)	3.5
Permeability (A.F.A.)	125.0
Green Shear (Lbs.)	2.4
Dry Shear (Lbs.)	35.0

6. If the permeability of a mixture of this type runs much lower than 125, say between 80 and 100, there is danger of scabbing unless the mold is very carefully rammed. With 125 as a safe low limit, permeability on green sand work can be run up to 400 or 500 without anything more serious than a somewhat rougher casting resulting.

7. For a general line of green sand work covering bench, machine and floor work running up to three thousand pound castings with metal sections of 2 in., a round grained sand, A.F.A. grain fineness 45, mixed to give a permeability of 250 works out very well. A sand of this type with a moisture content of 3.5 to 4 per cent can be rammed hard enough to prevent penetration and hold the casting true to pattern without any danger of scabbing.

NEW SAND PROPORTION

8. The question of the proportion of new sand in each mix is a matter worthy of considerable attention. Green sand facing mixtures varying from all new sand to all old sand can be prepared to give satisfactory results. There are two outstanding reasons for this wide difference in new sand additions. They are the quality of finish demanded and the efficiency of the sand reclaiming equipment. Where the ultimate in finish is required, there is nothing that compares with an all new sand mixture. However, when casting finish requirements are not so stringent, an all new sand facing is unnecessary and costly.

9. With reasonably good sand reclaiming equipment, very good results can be obtained with 25 per cent new sand. With better reclaiming equipment, a good finish may be obtained by using all old sand. In order that this may be done, the equipment must be capable of maintaining physical properties with only small amounts of new sand added through cores. Under this condition,

it is advisable to prepare all sand as a facing sand, thus simplifying the sand mixing and doing away with much extra handling. A single sand can also be prepared with fair reclaiming, by making small additions of new sand to each new mixture.

GREEN SAND FACINGS

10. To produce a green sand facing which is satisfactory to the molder and still meet laboratory requirements, a binding medium consisting of a combination of bentonite, fire clay and small amount of dextrine works out very well. This combination is particularly good where sand conditions make it impossible to obtain proper moisture and permeability conditions by using either bentonite or fire clay alone.

11. Bentonite, as a binder, increases permeability and lowers moisture but, at the same time, produces a mixture which dries out rapidly, making finishing difficult and offering insufficient resistance to the erosive action of the metal on the mold surface. Fire clay, on the other hand, lowers the permeability, keeps the sand workable longer and gives a tougher surface to the mold. Dextrine or corn flour are added to give increased surface hardness on short air drying.

DRY SAND FACINGS

12. For dry sand work of medium size, a facing sand with a moisture of 4.5 to 5 per cent, permeability around 180, green shear of 2.4 lb. and dry shear of 35 to 45 lb. works out very well. On heavy work it is advantageous to reduce the permeability to around 100 and in extreme cases, particularly corners and pockets in heavy metal sections, a permeability as low as thirty or forty is necessary to prevent penetration.

13. On dry sand work where high permeability is not required, fire clay should be used as the binder. Moisture should be kept high enough so the mold will not dry out in finishing and so that as high a dry strength as possible will be developed on the mold surface.

14. If the clay in itself does not produce sufficient dry strength, this can be increased by the addition of a small amount of dry core binder. By adding a moderate amount of silica flour to the above combination, the permeability can be lowered, less clay is required and the mold is given the advantages of semi-core surface.

PERMEABILITY AS AFFECTED BY RAMMING

15. With respect to permeability of both molding and core sand, the effect of hard ramming should not be disregarded. Table 1 shows the decrease in permeability of various mixtures on hard ramming. The tests were made by using a regular A.F.A. laboratory rammer on samples mixed with four different types of binder. Each sample was given a total of fifteen blows with the rammer while the permeability was checked after each three blows. A sample of molding sand when given fifteen blows with a rammer is approximately as hard as the sand would be when rammed hard in the mold.

16. One sample of each batch was dried after the usual three blows and another one of each batch after fifteen blows. The object of this was to determine the change in permeability of a sand after baking and the comparative results show up in the double columns under each heading in the table.

Table 1

PERMEABILITY AS AFFECTED BY VARIATIONS IN RAMMING

NUMBER OF RAMS	CLAY MOLDING SAND		SILICA-OIL CORE SAND		DRY BINDER SILICA SAND (CORES)		CLAY-BENTONITE MOLDING SAND	
	GREEN Perm.	DRY Perm.	GREEN Perm.	DRY Perm.	GREEN Perm.	DRY Perm.	GREEN Perm.	DRY Perm.
3	90	120	7	10	32	50	180	250
6	52	..	3	..	18	..	105	..
9	39	..	3	..	13	..	70	..
12	35	..	2	..	9	..	58	..
15	32	39	2	2.5	7	13	39	85
Per Cent Drop in Perme- ability	64.4	67.5	71.4	75.0	78.1	74.0	78.3	66.0

17. By the percentage of loss in permeability shown by Table 1, it can be seen that both core and molding sands are effected similarly. These results indicate that any sand mixture is flexible enough to be used over a wide range of metal sections when it has been properly rammed.

LOW PERMEABILITY AND HIGH MOISTURE

18. When using low permeability and a high moisture, greater care must be taken in the drying of the mold or a scabby casting will result. On such work, a round grained sand of A. F. A. fineness 45, the same as for medium green sand work, is advisable. On moderately heavy work running up to about three tons, a facing sand using $7\frac{1}{2}$ per cent of new sand produces ex-

cellent results. This means that the old sand is kept in fairly good condition. On heavier work, it is safer to use new sand in greater proportions, running up to all new sand on extremely heavy work.

CORES

19. Core sand mixing obviously presents a somewhat different problem than molding sand. Cores must be made hard enough to permit rough handling without breaking or having the edges rubbed off, and also to resist the washing action of the metal where they are used close to the gate. Such hardness must be produced as far as possible with binders that will soften somewhat and permit the core to collapse before the metal solidifies. In this way, the metal is permitted to shrink without hot tears and the cores can be cleaned out easily.

Green Strength

20. A core sand should have only as much green strength as is necessary to prevent the cores from sagging. Keeping the green strength as low as possible, we find that the sand flows much better and is more easily rammed into corners and pockets. The moisture content of core sand should run as high as possible so that the maximum hardness may be obtained from the binders used. In other words, high moisture makes a harder and denser core.

Permeability

21. Permeability in core sand is of more importance and requires better control than in molding sand. Generally speaking, core sands are mixed through a lower range of permeability than molding sand. In fact, where conditions are unusually severe, it is necessary to use sand with a permeability as low as one.

Sand and Binder

22. On small cores for bench and production work, a relatively uniform round grained sand, A.F.A. fineness 53, gives excellent results. This is the same sand as used for green sand facing on bench and squeezer work. On work of this type, where good sharp edges must be held and cores are subject to rough handling, an all new sand mixture using oil as a binder works out best. Clay content of the sand used may safely run up to one per cent. If washed sand is used, an addition of 0.75 per cent by weight of bentonite and a similar addition of cereal binder pro-

duces a sand which works better in the core box than when all cereal is used to produce green strength. The clay requires slightly more oil, but produces a sand which is easy flowing and not nearly so pasty as an all cereal mixture.

23. This mixture gives a permeability of about 60 and is satisfactory for metal sections up to one inch. As metal sections increase, permeability must be lowered to prevent metal penetration. Fig. 1 showing permeabilities for various metal sections indicates the writer's experience with core requirements. The permeabilities shown in Fig. 1 apply to cores which are used in pockets and projecting corners and also internally.

General Core Consideration

24. On flat surfaces, extremely low permeability need not be used even on heavy work. On larger cores for medium heavy work, a facing sand containing as low as ten per cent new sand gives excellent results when a dry binder is used. As long as oil is not used as a binder, the same conditions govern new sand proportions for cores as for molding sand. These conditions are the efficiency of the sand reclaiming equipment and the casting finish demanded.

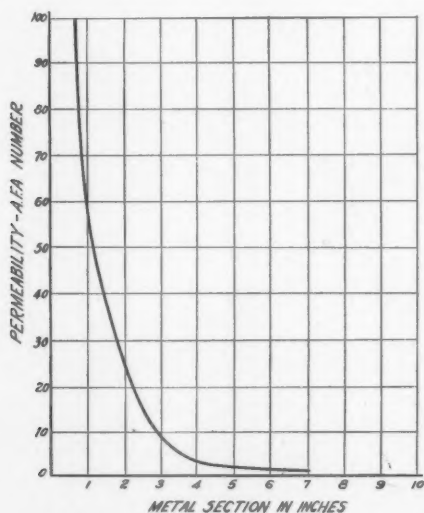


FIG. 1—CORE SAND PERMEABILITY FOR VARIOUS METAL SECTIONS.

25. Another factor is the amount of clay remaining in the old sand. A clay content of five per cent or less in the mixture is not detrimental to the casting surface and gives needed green strength. A small amount of clay also helps to increase dry strength and lowers permeability. However, when clay runs over this amount, the sand has a tendency to burn onto the casting, giving a poor surface.

26. Cores using dry binders should be used wherever practicable because of the advantages of both lower material costs and quicker drying. On heavy work where large core surfaces are exposed to the action of the metal for the time required to fill a large mold, new sand, silica flour and oil produces the cleanest casting. The greatest disadvantage in using this sand is that extreme care must be taken in the drying of the cores to make certain that the oil is completely oxidized. Even small cores require a long drying period at a moderate temperature in order that they may be baked all the way through.

27. If cores which have not been thoroughly dried are used, not only will the metal penetrate the corners and pockets, making it next to impossible to clean the casting properly, but gases formed in the core when in contact with the metal will force sand from the core surface, thus leaving scabs and sand accumulation on the cope side of the casting. The same condition will result when thoroughly dry cores are placed in hot dry sand molds from which all the moisture has not been removed. Such hurry up placing of cores permits the hot moisture vapors from the mold to enter the core through the vent holes and condense there, giving the same effect as an undried core. Similarly, when a core is placed in a dry sand mold and the mold is then dried in the oven, unless the drying job is thorough and complete, the remaining moisture will come up through the vent and be absorbed into the core.

28. These last few remarks are getting away from the subject of sand control in the strict sense of the term, but tend to show that in order to obtain the fullest results from sand control, the same care that is used in preparing the sand must be used in general molding and coremaking practice. A sand laboratory may be ever so well equipped and the person in charge may be ever so conscientious but, if the cooperation which should exist between him and the various department foremen is not there, the whole program will probably amount to just a futile item of expense.

DISCUSSION

Presiding, JOHN HOWE HALL, Taylor-Wharton Iron and Steel Co., High Bridge, N. J.

MAJOR R. A. BULL: I was very favorably impressed by the logical way in which the author presented his definite views on the subject. I do not feel inclined to take any exception to any of these assertions that were made. I assume that if Mr. Fuerst subsequently finds some of these values do not fit a given situation, he will be broad minded enough to change his opinions. I have changed a good many opinions about sand in the past 15 years, and I am not through changing them yet. We can still throw a lot of light on a very abstruse subject.

I am particularly pleased when I see men come up through apprentice courses or otherwise, who have the intelligence and the disposition to delve into this subject because it underlies, I suppose, 85 per cent of the troubles the steel foundryman has.

H. L. CAMPBELL¹: I would like to raise a question regarding a statement in paragraph 20 of this paper—"In other words, high moisture makes a harder and denser core." The results obtained in our investigations of oil-sand cores are contrary to this statement. The purpose of adding water to oil-sand mixtures is to cause an increase in the volume of the sand and to improve the green strength of the sand mixture. As water is added to clean dry sand, the volume is increased to a maximum of about 10 per cent as the moisture is raised to 4 per cent of the volume of the sand. Further additions of water cause a decrease in volume until, with 40 per cent water, the volume occupied by the sand is the same as the original volume of the dry sand. One of the reasons that water is added to oil-sand mixtures is to cause the sand to swell and thereby improve the permeability of the mixture.

Another reason for adding water to oil-sand mixtures is to increase the green strength of the mixtures. Anyone who has tried to mold clean white sand at the seashore has observed that the sand which is just damp can be formed to shape quite well, but sand which is very wet does not hold the shape into which it was formed.

The results of carefully conducted tests have repeatedly shown that the more water added to oil-sand mixtures, the lower were the strengths of the baked cores. The reason for this condition is that some of the oil, which is distributed throughout the sand mixture, is removed mechanically by the water vapor as it leaves the cores. The viscosity of the drying oil is decreased during the preliminary stages of the baking process. With the oil ratio constant, the more moisture added to the mixture, the lower will be the strengths of the cores.

MAJOR BULL: May I ask the speaker what percentage of moisture is covered by the range he is talking about?

MR. CAMPBELL: From zero to 10 per cent. The strength of the baked cores decreased as the percentage of water increased. The maximum

¹ American Hoist & Derrick Co., St. Paul, Minn.

green strength was obtained with about 4 per cent moisture. As more water was added to the sand, the green strength decreased.

MAJOR BULL: Did you find that experience in connection with all core binders?

MR. CAMPBELL: No. This discussion relates only to oil-sand mixtures. When water-soluble binders are used, sufficient water must be added to develop the full characteristics of these binders.

MAJOR BULL: What about the combination of binders that we have to use in most cases where we add something besides oil to give green strength?

MR. CAMPBELL: Then you must compromise on a water ratio satisfactory for the combination of binders. When gelatinized starch binders are used, about 12 per cent water will produce the most favorable condition to develop high green strength.

C. W. BRIGGS: Did you try any emulsification process or just the water and oil content?

MR. CAMPBELL: The statements made refer to oil and water added separately to the sand and not in the emulsified condition. It is possible to obtain good distribution of the oil by first preparing an emulsion of the oil with water.

In connection with the remarks on the effect of water, it is interesting to note that swelling is not produced when oil alone is added to dry sand. When oil is mixed with the sand first and then the water is added, the volume of the mixture increases. This is the most favorable order for adding the ingredients in the oil-sand mixture.

MAJOR BULL: I believe my questions clarified the point the speaker was making. The foundryman making cores often finds he has to have a certain amount of green strength. If it were possible to add oil alone as a binder, it would give us the best bonding strength. But we have to compromise. In that compromise, which is so common in the foundry, it has been my experience that up to about 7 to 8 per cent water in the core does develop most satisfactory dry strength. I do not mean to say that would hold true if we depended only on the oil binder. But we are not depending upon the oil binder alone.

Developments In Melting Malleable Cast Iron

By W. R. BEAN,¹ HARVEY, ILL.

1. While the title assigned might give license to survey the early history of the malleable industry, the temptation to do so will, for the sake of brevity, be resisted and this discussion confined generally to the period since 1912 or thereabouts. Prior to that date, malleable iron was melted in three types of furnaces; the cupola, the reverbatory or air furnace and the open-hearth furnace.

2. Cupolas for malleable and for gray iron were, and are today, of substantially the same design, with difference in operating practice the principal distinction. The higher temperature requirement of malleable calls for the use of more coke and metal to coke ratios are of the order of 5:1 to 7:1. Greater care in making up the charge, and in charging, for malleable is essential for chemical analysis control.

3. Air furnaces prior to 1914² were coal-fired by hand or oil-fired, with a least 90 per cent of the output from hand-fired furnaces. Hand-fired furnaces were of two general types: the "camel back" with forced draft, and the straight roof with natural draft.

4. The late Benjamin J. Walker, Erie Malleable Iron Co., Erie, Pa., was the first to employ the natural-draft furnace extensively, and was its principal exponent for some years. This furnace of 30 to 40 tons capacity, as early as 1900, was the largest furnace in use in the industry until about 1925. Air furnace heats of 75 to 80 tons are now regularly produced with very satisfactory results thermally, chemically and metallurgically.

5. Having given a bit of history of the large capacity air furnace, it may not be out of place here to mention what we believe to be the oldest furnace in operation today, at least the furnace in the oldest operating malleable foundry, Belcher Malleable Iron Co., Easton, Mass. This plant has been in operation for more than 100 years. The melting furnace equipped for pulverized coal firing several years ago had a capacity, hand-fired, of

¹ Vice President, Foundry Equipment Division, Whiting Corp.

² *Application of Pulverized Coal to the Air Furnace*, Bean, W. R., TRANS. A F. A., vol. 26, (1917), pp. 337-344.

NOTE: Presented before Malleable Session of the 41st Annual Convention, Milwaukee, Wis., May 5, 1937.

5 tons, which is now melting one heat per day of approximately 8 tons.

6. The open-hearth furnace was never popular in the malleable foundry although this is still the type used in two foundries in the Pittsburgh district. Several attempts to employ this furnace on large scale melting of malleable iron proved disastrous and the furnaces were replaced by air furnaces. With the acknowledged merit of the open-hearth in steel melting, the writer's answer to the failure on malleable was "the malleable melter does not know the open-hearth furnace and the steel melter does not know malleable iron."

7. Two outstanding developments in melting malleable cast iron had their inception about the same time, 1912 to 1914, although a number of years passed before either was employed extensively. The first of these was duplexing and the second pulverized coal firing.

DUPLEXING

8. Duplexing of malleable iron was first practiced in 1912 and credit for this should go to W. G. Kranz, The National Malleable & Steel Castings Co., although the first attempts, which involved cupola and electric furnace, were not successful and led directly to the triplex patents issued to Mr. Kranz.

9. The excessive carbon content of cupola metal to produce, through duplexing in the electric furnace, the then standard carbon range of 2.40 to 2.60 per cent carbon for railway and other castings of heavy section, accounted for failure of this process and the introduction of the Bessemer converter, to reduce carbon in a portion of the electric furnace hot-metal charge, as the third unit for triplexing.

10. Credit for the first successful cupola and malleable duplexing installation we believe should go to V. S. Durbin, who, in 1927, installed a cupola alongside the air furnace in the plant of Southern Malleable Iron Co., East St. Louis, Illinois. Production from this unit has continued since the original installation.

11. Reduction of carbon from the minimum obtainable from the cupola is still the principal problem in the process but is being successfully met today in duplexing through the air furnace, by steel additions in one large foundry, and in duplexing through the air furnaces (oil-and-pulverized-coal-fired) there be-

ing a total of 12 duplexing installations now in regular operation, producing malleable iron.

12. Approximate tonnages produced by the different methods in use are shown in Table 1.

Table 1
ESTIMATED TONNAGE CAPACITY CASTING PRODUCTION
OF MALLEABLE IRON INDUSTRY

Melting Method	Annual Capacity Tons	Per Cent of Capacity
Pulverized-coal-fired air furnace.....	716,750	59.8
Hand-fired air furnace.....	61,600	5.2
Cupola	99,200	8.3
Cupola and electric furnace duplexing.....	100,000	8.3
Cupola and air furnace duplexing.....	152,100	12.7
Oil-fired air furnace.....	36,100	3.0
Open-hearth furnace	33,000	2.7
	<hr/> 1,198,750	<hr/> 100.0

13. A not generally recognized metallurgical fact should be mentioned here because of the significance which this has in the duplexing field. This relates to the carbon effect on graphitization in solidification and also the carbon effect upon physical properties of the metal. As the writer is not now associated with a producer it is necessary for him to speak from general observations rather than from actual quantitative data on these points. As a result of rather extensive observation, he would estimate that for a given section of metal or weight of castings, carbon may be 10 to 20 points higher in duplexed metal than in direct-melted metal, without deterioration in quality.

14. The writer shall not soon forget the suspense under which he labored waiting for castings to come from the anneal in the first cupola and air furnace duplexing installation which he put into operation. Castings of 2.70 carbon, which he knows would have been worthless produced from direct air furnace metal, were normal in all properties and of superior quality. He was not one who early accepted duplexing as a quality process for malleable iron, having had 25 years schooling in the air furnace process and having been taught that high quality was not to be found outside this process. 'Tis said that "honest confession is good for the soul" and we here confess our present conviction of its real merit.

15. The metallurgical difference between duplexed malleable and direct-melted malleable iron of similar compositions is one of the conundrums of the malleable process. It is our opinion that the difference is to be accounted for by the difference in charge materials used in the two methods, more steel scrap and less pig iron being used in the duplexed metal than in the direct melted metal. In other words, "inheritance" from the charge affects the carbon condition or dispersal in the structure.

16. The urge to duplex is of course economic and involves two main factors: first,—lower cost of metal at the spout and, second,—provision of continuous metal to supply the mechanized foundry or those pouring continuously, although following the conventional molding methods except that molders do not pour their molds. That operation is done in the latter case by a "pouring gang."

17. The question frequently asked as to minimum tonnage which will justify duplexing cannot be answered without qualification because there are so many factors involved. There must be continuous pouring and a divorce of molding from pouring. The advantage is greatest where mold conveying is employed. In general, it may be stated that a daily melt of 30 tons will hardly justify duplexing in comparison with direct melting in the pulverized-coal-fired air furnace, but this is near the dividing line.

PULVERIZED COAL FIRING

18. Earlier reference has been made to pulverized coal firing of the air furnace and discussion here of that development would be a repetition of the facts contained in the reference. The extent to which the air furnace is still employed in melting malleable iron is shown by the data of Table 1, and the proportion that is now pulverized-coal-fired is evidence of the economy and merit of this method of operation.

19. The introduction of the Brackelsberg (rotary) furnace, which is a member of the air furnace family, into malleable melting in 1934, paved the way for meeting the needs of the growing demand for quick-anneal malleable, the low carbon content of which precludes the possibility of production in the cupola and air furnace duplexing process. The Brackelsberg and "cradle" furnace combination, the latter a recent development and also a member of the air furnace family, provides the facility for a continuous supply of highly superheated metal necessary for this

lower carbon product and for conveyor molding. Here we are forced to the combination of batch melting units and a special type of holding unit because there is today no continuous melting furnace which will produce iron of a carbon content of less than 3.00 per cent or thereabouts.

DISTINCTION BETWEEN DUPLEXING FURNACE AND HOLDING FURNACE

20. A distinction should be drawn between "duplexing furnace" and "holding furnace" as the functions are not the same in some fundamentals. We differentiate on the basis that in a



FIG. 1—VIEW OF 5-TON BRACKELSBURG FURNACE, SHOWING PULVERIZED COAL BURNER STACK, CONNECTING CAR, RECORDING PYROMETER AND PRIMARY AND SECONDARY AIR, AND TILTING MECHANISM.

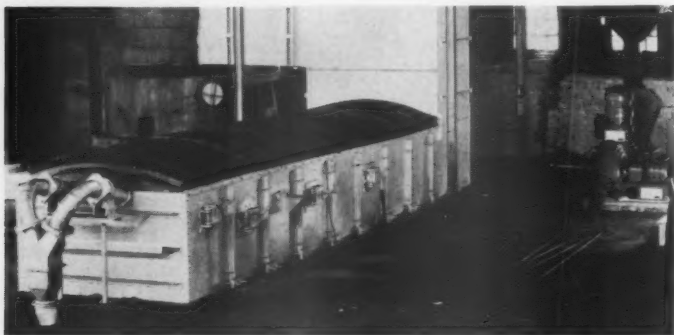


FIG. 2—AIR FURNACE (15-TON) WITH PULVERIZER AND POWDERED COAL FEED CONNECTION, USED IN MAKING CHILLED IRON ROLLS, HIGH TEST GRAY IRON AND BRONZE CASTINGS.



FIG. 3—PULVERIZED COAL-FIRED CRADLE FURNACE (10 TONS) USED IN CONNECTION WITH A BRACKELSBURG FURNACE UNIT.

duplexing furnace there are changes in the metal treated, such for example as the essential reduction of carbon in the cupola and air furnace combination for regular malleable compositions. However, in the Brackelsburg and cradle furnace combination for quick-anneal malleable and its cousin, copper-silicon steel, metal is delivered to the cradle furnace with the desired composition and the function is simply to hold this at suitable degree of superheat.

21. Under favorable conditions, the cost of metal at the spout for quick-anneal malleable in substantial tonnages should not be much in excess of that for cupola and air furnace duplexed metal. The Brackelsburg furnace is a very efficient melting unit with low oxidation characteristics, permitting small content of pig in the charge and delivering metal at high temperature.

22. An outstanding fundamental feature of the rotary furnace is that this is the only type of furnace in which the charge and the bath are heated from the top and the bottom at the same time. The result is low fuel consumption with rapid melting and superheating due to passing of the superheated lining under the metal.

CRADLE FURNACE

23. The cradle furnace is a more efficient unit than the regular air furnace, having a thicker roof, and the fuel per ton of metal is lower than for duplexing an equivalent hourly tonnage of regular malleable metal.

24. This furnace developed to serve as a balance wheel in

continuous pouring foundries is fired with pulverized coal and serves as a large reservoir or mixer for hot metal from other melting units. It is designed to tilt or rock "cradle-wise" by power and receives metal while filling distributing ladles. Arranged for lip delivery, expensive and troublesome tap-hole blocks are eliminated and faster delivery through a large stream means less temperature drop between furnace and ladle.

25. In conclusion, it may be stated that the malleable foundry industry is well cared for at the present time in its melting equipment to meet the varying needs. However, with the indicated increasing requirement for larger tonnage of lower carbon metal in the future, a furnace to provide continuous direct metal of carbon content from 2.50 per cent, the low limit in cupola air furnace duplexing, down to 1.00 per cent which may be a requirement of the industry in the not distant future.

DISCUSSION

Presiding . . . L. N. SHANNON, Vice President, Stockham Pipe Fittings Co., Birmingham, Ala.

JOE T. GILBERT: May I ask the temperature of the iron at the spout in the duplexing process?

MR. BEAN: The temperature at the spout of the air furnace can be anything up to 2850° F.

MR. GILBERT: I meant at the cupola.

MR. BEAN: That is a very interesting question because it brings out one point that I did not cover. We advocate melting just as cold as possible in the cupola for temperature necessary to deliver metal to the furnace. We like to see just enough temperature to have the fluidity that is required to get the metal into the furnace. There are several reasons for this. In the first place, coke costs generally about twice as much per ton as coal. In the second place, the lower the coke, the lower the carbon and the lower the sulphur; particularly is it desirable to melt cold from the standpoint of the sulphur content.

To answer your question specifically, I would say around 2500° to 2550° F.

MR. GILBERT: What is considered a good coke ratio?

MR. BEAN: Taking all the coke received into the plant and taking the tons of iron charged to the cupola, one plant went through last year using 183 pounds of coke per ton of iron melted. That figure includes bed and everything. This is on a melt which last year varied from 150 to 200 tons a day.

MR. GILBERT: Which is the cheaper method of duplexing,—air furnace or electric furnace?

¹ Stockham Pipe Fittings Co., Birmingham, Ala.

MR. BEAN: That will depend upon the cost of electricity. I doubt if there is any place where the cost of electricity is low enough to actually justify the use of electric furnace if you consider solely from the basis of the cost of metal at the spout. There may be other conditions which indicate the desirability using the electric furnace, but taking it purely on a cost basis, I do not think it is possible to duplex with the electric furnace at as low a cost as with the air furnace.

J. H. LANSING:² In connection with the comment concerning the tendency not to graphitize when the metal is poured in the duplexing process, is there not another factor that has not been mentioned there?

The one that has been mentioned is the use of a high percentage of scrap. Generally, when a duplexing installation is made, the metal is conveyed to a greater distance because of the greater production of metal from one unit. Therefore, necessarily, the temperatures run higher. The higher temperatures are also a considerable factor in decreasing the tendency to graphitize on solidification. I believe that is a fact that has been brought out in the experience of a good many people in the past and it was, I believe, also mentioned by Mr. Schneidewind in his paper* yesterday.

MR. BEAN: I believe that that is a correct statement of a condition that has not been mentioned. I would say that taking the average metal duplexed in the air furnace, it is probably 50° to 75° higher temperature, leaving the furnace, than direct melted malleable. That figure fairly accurately represents the difference, and undoubtedly the actual conditions in solidification are benefited by the higher temperature at which the metal is tapped.

I would like to add just one thing in connection with this question, which relates to the amount of decarburization and the reason it is not possible or practicable to duplex the lower carbon metals. There is a fairly definite relation between carbon removal and surface exposure. We have one job averaging about 20 tons per hour and another about 10 tons per hour. The two furnaces have a hearth area of approximately 210 sq. ft. In the case where the rate is 10 tons per hour the carbon drop will run between 0.40 and 0.45 per cent. In the other case, with the 20 tons per hour, the carbon drop will run between 0.20 and 0.25 per cent. This has been confirmed by several other installations, indicating a fairly definite relation between hearth area and carbon reduction.

The length of time that the metal is in the furnace also is a most important factor. In each of these cases, the furnace bath is of approximately 20 tons. Therefore, the furnace that is duplexing at the rate of 20 tons per hour has the metal in the furnace an hour. In the furnace, that is duplexing at the rate of 10 tons per hour, the metal is in the furnace two hours. That is the correct explanation of the difference in carbon reduction with the same tonnage of bath.

The point that I want to make here is this: That if the bath area is doubled, the carbon reduction will be doubled. However, there is a practical limit to the size furnace that we think is desirable for duplexing.

² Shop Practice Engineer, Malleable Founders' Society, Cleveland.

* R. Schneidewind and A. E. White, *Properties of Fully Annealed and Heat Treated Malleable Irons*, Trans. A.F.A. No. 3, Vol. 8, June 1937, pp. 1-27.

Therefore, we hold to a reasonable dimension and get the result that can be obtained with these limitations.

The table below is based on observations in several installations:

Tons Per Hour	Size	Area Sq. Ft.	Lbs. Metal Per sq. ft. Per Hour	Sq. Ft. Per ton Per Hour	Probable Carbon Reduction Per Cent
25	8'-2" x 40'-6"	331	151	13	0.26
30	"	331	181	11	0.22
10	7'-0" x 30' approx.	210	95	21	0.42
20	7'-0" x 30' "	210	190	10.5	0.21
5	4'-6" x 15'	67.5	148	13.5	0.27

W. G. CONNER, JR.:² In your experience with cupola melting of malleable iron, have you been able to develop any figure on the percentage of carbon pickup? By that I mean the total amount of carbon figured in the charge and the amount coming out of the spout picked up from the coke in the melting?

MR. BEAN: I do not have any actual figures on that. Cupola operators do not figure carbon in their heats in the manner air furnace operators do. On any air furnace, that is one of the first fundamentals,—how much carbon is removed?

MEMBER: About what is the percentage or number of foundries still using the camel back type of furnace?

MR. BEAN: At the present, the camel back furnace is used only in hand firing, and 5.2 per cent of the capacity of the industry is hand fired. I know of only two or three plants which today are using the camel back type of furnace.

The camel back air furnace is as efficient and possibly a little more efficient than the straight roof air furnace when hand fired. The reason which prompted me years ago, when operating hand fired furnaces, to get away from the camel back furnace was the difficulty of maintaining the roof at the low point. The straight roof is much simpler to maintain, and for that reason, we went to the simpler form of roof.

² Foundry Division, Walworth Co., Greensburg, Pa.

Cupola High Test Cast Iron

By R. S. MACPHERRAN*, MILWAUKEE, WISC.

Abstract

Defining high test cast iron as an iron having over 50,000 lbs. per sq. in. tensile strength, the author describes the procedure used in his company's foundry to produce such metal. Effects of certain alloy additions are discussed although it is recognized that high test iron can be made without alloy additions. Cupola melting procedure is described, especially as it relates to carbon control which is said to be most important. Test bars and factors affecting test results are considered from various angles such as tensile and transverse strengths and stress-strain under load. In conclusion duplexing is discussed.

INTRODUCTION

1. Before discussing high test iron, it is first necessary to define it. We have always held that only those irons which give a tensile strength of over 50,000 lbs. per sq. in. are to be called high test and we will therefore so limit the range in this discussion.

2. The making of high test iron has been described by so many, and with such a varied procedure that it is not possible to refer to them all, and it would be unjust to mention only a few, we are, therefore, in this paper, giving as far as possible, only our own results and our own cupola practice. Our practice could, undoubtedly, be improved, but it fits our needs.

3. We use our regular cupolas without change from ordinary iron practice and while improvements might be made on the standard cupolas now in operation in many foundries, we have no doubt that good high test iron can be made in practically any of them. It should be recognized that high test iron is not limited to one composition, but is usually adjusted to meet the needs of the operating foundry and the demands made on their castings.

* Chemist, Allis-Chalmers Mfg. Co.

NOTE: This paper was presented before the Gray Iron Session of the 41st Annual Convention, Milwaukee, Wis., May 4, 1937.

Machinability a Factor in High Test Irons

4. The expense of machining high test irons also enters into the picture and often alloys are added to increase the machinability where such additions are not required to obtain the desired strength. In general, high test iron is machined at about the same speed as a steel casting.

Alloyed and Non-Alloyed High Test Iron

5. It should first be recognized, that high test iron can be produced without as well as with the addition of alloys. If any foundryman wishes to increase the machinability and perhaps close the grain of his iron, he may add $\frac{1}{2}$ to 1 per cent nickel. Or he may use copper for somewhat the same purpose. In former years copper was thought to make iron red short. We have now made many tests at temperatures up to 1200° F. of irons containing 1 per cent copper and found no greater loss of strength than usual in other irons.

6. Assume, for example, that an iron without alloys gives a tensile strength of 50,000 lb. per sq. in., adding 1 per cent nickel will usually bring this to 55,000; adding 0.30 molybdenum with the nickel should increase this to nearly 60,000 lbs., with a better impact value, and increasing the molybdenum to 0.5 will raise it still further. If additional hardness is desired, powdered ferrochromium may be added in the spout. In considering any additions, however, one should bear in mind the increased cost.

7. We have made in the "as cast" condition, tests of over 86,000 lbs. per square inch; but we would not, of course, guarantee such strength in castings.

MELTING AND MOLDING PRACTICE

8. The cupola we most often use is a 54 in. inside dia. cupola, having 6 tuyeres in one row. These tuyeres are 19 in. long by 5 in. in height, and are equally spaced around the cupola. The upper edge is 19 in. above the sand bottom.

Coke Bed

9. The coke bed weighs 2,300 lbs. and the iron charges 3,000 lbs. There is an average of about 325 lbs. of coke used between the charges.

Iron Charges

10. The iron charge consists of 80 per cent steel; 8 per cent to 10 per cent return high test iron scrap; 8 per cent silvery pig; 1 to 2 per cent Northern pig (Si. 2 to 3 per cent) and 2 per cent ferro-silicon. In the spout there is added 3 lbs. of ferro-manganese silicon for each thousand lbs. of iron in the ladle. This ferro-manganese silicon contains 50 per cent silicon and 25 per cent manganese, the remainder being iron. After charging, the cupola is allowed to stand an hour before the blast is put on.

Composition

11. The resulting castings analyze about: Silicon 2.25; sulphur 0.100; manganese 0.80; phosphorous, under 1/10 per cent; and chromium 0.20. The total carbon is usually around 2.80, although the first ladle will sometimes exceed that amount.

Carbon Absorption

12. To avoid this high carbon of the first iron, we often put in 2 or 3 charges of a mixture without scrap and using about 87 per cent steel. As this iron must be poured hot, we have made no effort to reduce the amount of coke on the bed or between charges. In our experience, the absorption of carbon is one largely of opportunity, and a high bed and a large amount of coke in the cupola tends to increase the carbon in the ladle.

13. Short taps are made, and the iron kept in the cupola as short a time as possible. While a high temperature probably increases the absorption of carbon, we always melt very hot.

14. The blast pressure is 6 ounces. About 100 lbs. of limestone are used per charge. The by-product coke used contains up to 8 per cent ash and 0.7 per cent sulphur.

Gates and Risers

15. The risers are made larger than usual and the iron flushed into the mold as rapidly as possible. This metal has a short freezing range and very little internal shrinkage. Short gates should be used.

Adding Nickel

16. We do not use nickel shot in the spout, but where nickel is added we use it as ingot nickel either in the cupola or in the ladle.

17. When adding nickel in the ladle, it is always preheated either by a charcoal fire or a torch to dull redness. In this condition it dissolves quickly in the stream of iron. Wherever possible, we avoid adding cold alloys in the ladle.

HEAT TREATMENT

18. This iron is quite sensitive to heat treatment. It can very easily be hardened by quenching in oil, and fairly complicated castings can be so treated. The hardness is so raised to equal that of chilled iron.

19. In its "as cast" condition it is, of course, weakened by annealing at 1550° F. A specimen from a transverse bar, for example, broke at 82,700 lbs. A second specimen cut adjacent to the first specimen, but annealed at 1550° F. for 2 hours and cooled in the furnace, broke at 52,400 lbs.

WELDABILITY

20. This iron can be welded easily and no difficulty has been found in this regard.

POSSIBLE SIZE OF CASTINGS

21. There are no foundry reasons which limit the size of the castings produced. We have made them 57 tons in weight.

TEST BARS

22. All our tests are made on test specimens machined from the standard arbitration bars which are first broken transversely and the tension bar then cut from the broken half. Impact tests are often made on a piece cut from broken half of transverse bar. They are machined to 1.100 in. round and broken on a modified Charpy Machine with a 6 in. span. These tests are, of course, only comparative.

23. Test bars from a small ladle are usually superior to those from a large one. It fills quicker and is therefore hotter. It is also easier to dip out a clean test ladle full of iron.

Carbon Control and High Strength

24. It must be remembered that a low carbon is a requisite of high strength, and that, as the carbon gets lower the metal more nearly approaches steel in its properties, and is therefore, harder to run. We do not like to get the carbon below 2.50 and prefer it from 2.70 to 2.85. On a consecutive run of 200 bars for ordinary

castings the tensile strength averaged 55,000 lbs.; using molybdenum raised the average tensile strength to nearly 60,000 lbs. per sq. in.

Tensile Strength and Transverse Strength

25. It might here be noted that when comparing this iron with a specimen from the mixture containing 25 per cent steel, we find that the tensile bars show in proportion, a much greater strength than do the transverse bars. For example, taking specimens from both types of iron, those from the high test will be 75 per cent higher in tensile strength but only 30 per cent higher in transverse load.

26. The transverse bars, of course, are broken rough and part of this difference may be ascribed to the irregular section or to the minute defects left on the under side of the bar and acting like nicks in hard steel. It would be very interesting to try machining transverse bars in order to see whether this would overcome any of the above discrepancies. The same is somewhat true of the impact test.

Corrosion Resistance

27. We have no data on its comparative resistance to corrosion, but doubt if the amount of alloys usually added would greatly delay any chemical action.

Fatigue Value

28. The fatigue value is about one-half the tensile strength¹.

Dendrites

29. One of the things to be avoided is the presence of too many dendrites. These are apt to occur, and when present, will leave lines of possible cleavage and sometimes even cracks in the outer surface of the casting. Their presence is at least lessened by the addition of small amounts of ferro-silicon to the ladle, and the presence of chromium.*

Elongation

30. There is, of course, practically no elongation in high test iron. It is cast gray and always contains some flake graphite. Cast

¹ Koppers, J. B., "The Status and Fatigue Properties of Some Cast Irons." Proceedings, American Society for Testing Materials, Vol. 28, (1928), Pt. 2, pp. 174-197.

* P. Bardenheuer and K. L. Zeyen, *Die Überhitzung von Giesseisen*, Mitteilung, Kaiser Wilhelm Institut für Eisenforschung, No. 130.

irons showing elongation are usually cast white and heat treated to break up most, or all, of the cementite.

Stress Strain

31. To illustrate its action under load, we include a stress-strain diagram (Fig. 1) showing effect of stressing in tension. A standard Navy bar was used, a strain gauge was attached and the load applied, reading the extension as the load increased. (The

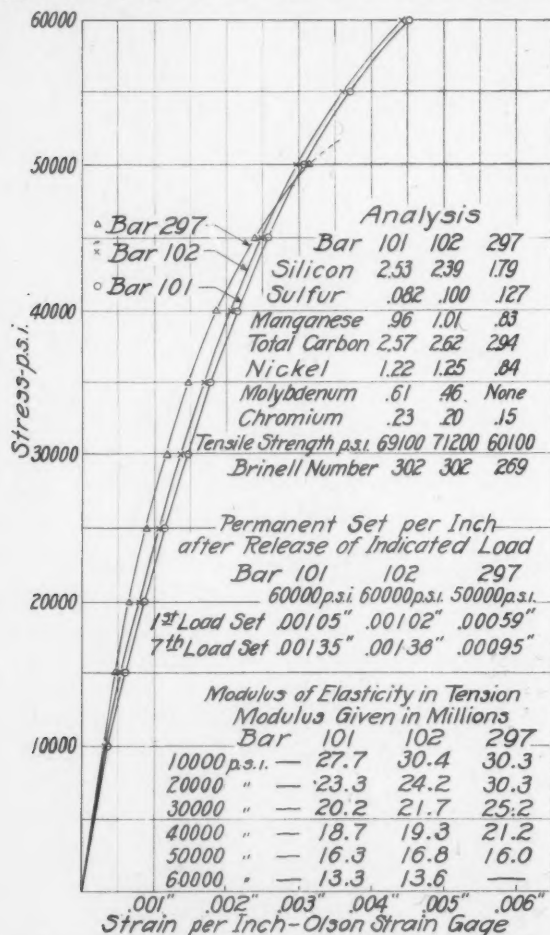


FIG. 1—STRESS-STRAIN DIAGRAM OF HIGH TEST CAST IRON.

strain gauge was of the sensitive type, one division equaling 0.000066 of an inch.) The load was then removed, and the permanent set measured. This loading and releasing was done 7 or 8 times and the specimen finally loaded to destruction. These curves show the resulting strain in the bars. As the loads go 80 to 86 per cent of the final breaking load, the lack of much permanent elongation is evident.

DUPLEXING

32. A word might be added here as to the duplexing from the cupola into a crucible. This is of value when the amount of special iron desired does not warrant charging it in the cupola. For example, a few hundred pounds of high test iron can be made by the following procedure.

33. Into an oil fired crucible holding 650 lbs. of iron, put about 125 lb. of clean steel; 10 lb. of ferro-silicon; (50 per cent silicon) and if desired, 5 lb. nickel. Heat for 20 to 30 minutes, or until contents are red hot; then fill to the 600 lb. mark with melted iron from the cupola. This cupola iron to analyze—silicon 2.25; carbon 3.50. Heat for about 30 minutes, stir, and when temperature is right, tip from crucible into pouring ladle. This iron, owing perhaps to the flake graphite, in the melted cupola iron, will be of only 45 to 50,000 lbs. tensile strength; but it is easily and cheaply made. This procedure lends itself to the making of a few hundred lbs. of castings of almost any desired composition without the delay of melting cold stock in the crucible.

CAST IRON HAS BEEN IMPROVED

34. It does not seem to the writer, that the engineering profession has fully realized the change in cast iron. The old handbooks refer to it as cast iron—tensile strength 15,000 lbs. per sq. in. In view of the present developments in cast iron, it would seem to the writer that this material might often replace steel castings where ductility is not a controlling factor.

ACKNOWLEDGMENT

The writer wishes to acknowledge the cooperation of The Allis-Chalmers Manufacturing Company in granting permission to publish these results. He also wishes to acknowledge the aid of Mr. John Leisk and Mr. Julius Kleier of his organization for their assistance in the foundry during the development of this material.

DISCUSSION

Presiding: DR. JAS. T. MACKENZIE, American Cast Iron Pipe Co., Birmingham, Ala.

R. S. MACPHERRAN: In commenting on this paper, we wish to emphasize that it is addressed primarily to foundry foremen. For this reason I have kept as far as possible from theories and have shown no micrographs of any kind. We merely reported what we do and what we get. All bars are reported as cast without heat treatment.

Since the writing of this paper (last December), we have lowered the coke bed and now use but 2100 pounds of coke in place of 2300 pounds. The first iron appears to be hot and the carbon is lowered in the first few ladles.

The fifty consecutive specimens tested in the last few months *average* 62,000 pounds per square inch. Only a few of these contain molybdenum and almost all of them were of the standard one per cent nickel variety.

Table 1

HIGH TEST IRON. THE AVERAGE OF LAST 50 CONSECUTIVE TENSILE STRENGTH TESTS ON ARBITRATION BARS IS 61,980 POUNDS PER SQUARE INCH.

Tensile Strengths from Different Positions in Arbitration Bar.

Bar No.	Position Adjacent To	Tensile Strength Lb. Per Sq. In.	Ladle Capacity Pounds
101	Fracture	83,900	4,500
101	Gate	69,100	4,500
102	Fracture	82,700	7,000
102	Gate	71,200	7,000
342	Fracture	71,500	6,000
342T	Gate	59,100	6,000
363	Fracture	56,400	10,000
363T	Gate	54,600	10,000
364B	Bottom	66,500	6,000
364T	Gate	60,600	6,000

Table 2

TESTS ON ARBITRATION BARS CAST BEFORE AND AFTER POURING CASTINGS.

(One bar cast from filled ladle—the other cast from same ladle after pouring castings. About 14-minute interval between bars.)

Bar No.	Tensile Strength Before Casting Lb. Per Sq. In.	Pouring Temp. °F	Tensile Strength After Casting Lb. Per Sq. In.	Pouring Temp. °F	Type of Structure at 25 Dia.
352	68,100	.....	.....	.....	Some dendritic pattern
353	.....	.....	48,100	.....	No " "
356A	65,000	2618	.....	.....	Some dendritic pattern
356B	.....	.....	53,000	2437	Some " "
373A	62,600	2608	.....	.....	Some dendritic pattern
373B	.....	.....	47,500*	2428	No " "
374A	72,100	2660	.....	.....	Some dendritic pattern
374B	.....	.....	54,000	2477	Some " "

*Small flaw.

Certain irregularities in our tests seemed to indicate that the strength was affected somewhat by the position from which the tensile bar was cut. Our bars are the standard arbitration bar poured vertically. Upon investigation we find that the test specimen cut below the fracture of the transverse test bar is much stronger than the test specimen cut near the gate or upper end of the casting. It would seem to me, therefore, that it would be well for our committee to insert the sentence in our specification that tensile bars shall be cut adjacent to the fracture. This would tend to standardize the position from which these specimen were taken (See Table 1). We also tried the experiment of pouring test bars hot and cold (Table 2) and found a very decided benefit by pouring them hot. Both the tests would seem to indicate that considerable work could still be done on the test bar situation. It would appear that the main point in high test iron is to get a low carbon iron deoxidized as completely as possible and to pour it hot. Any tendency to pour cold results in loss of casting. We feel there is a great future for the heat treatment of cast iron and that it will follow the similar developments in cast steel. In our foundry we have done but little along this line as our castings do not lend themselves to heat treatment.

M. KUNIANSKY*: (*Submitted as written discussion*) I was particularly interested in Mr. MacPherran's comment (paragraph 26) regarding the possible variation in transverse load between the bar in the "as cast" condition, and one with the skin machined off. We are submitting some data (Tables 3 and 4) on bars comparing the two types. The machined bars were run on a surface grinder and were ground very true. Where the original dimension would be 1.20 in., the finished dimension is 1.15 in. We have not corrected deflections but we believe that it can be seen readily that most of them would be somewhat higher even though corrected. It is interesting to note that in all cases when both bars were sound, both in the "as cast" and in the ground condition, the load in the ground bar is much higher.

CHAIRMAN MACKENZIE: In reference to the point brought out in Mr. Kuniansky's discussion, I wish to say that I checked up on the two highest irons Mr. MacPherran submitted for the A.S.T.M. impact tests made some years ago, and whereas the ratio of the modulus of rupture to the tensile strength test on standard "as cast" bars dropped from 2.2 on 20,000 lb. per sq. in. iron to 1.2 on 60,000 lb. per sq. in. iron, the results from machined bars dropped only from 2.2 to 1.9. From this it can be seen that there is an enormous difference between the strength of the machined bar on this high test cast iron and the unmachined. We, of course, attribute that difference to the greater importance of small surface defects on the more rigid material. We all know that a nick in a wrought iron chain does not mean much, but one in a piece of tool steel is highly destructive.

E. F. GREEN¹: (*Submitted in writing*) It is realized that cupola practice is one of the most important factors entering into the production of high test iron. Does the author use a higher bed height than normal

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¹ Research Engineer, Metallurgical Dept., Axelson Mfg. Co., Los Angeles, Calif.

in making high test iron? What weight of air does the cupola blower supply for his practice?

It is noted that the author does not graphitize or inoculate the molten metal in the ladle. Presumably the small amount of ferro-manganese-silicon added in the ladle is for the lessening of dendrites. May it be deduced from the author's practice that the inoculation of molten metal in the ladle is not necessary in producing high test iron?

What is the author's theory concerning the proper graphite formation to obtain high test iron? It is the writer's belief that the amount, size and type of non-metallic impurities are one of the most important factors entering into the production of high test irons.

Table 3
PHYSICAL TESTS*

Comparison of transverse strengths of 1.20 in. diameter test bars in the "as cast" condition with bars of the same size poured from identical iron which had been surface-ground before testing.

Lab. No.	Surface	Trans. Load Corrected Lbs.	Defl. In.	Tensile Lbs. Per. Sq. In.	B.H.N.
4886-R	Ground	2952	0.276	—	—
4886-R	As Cast	2440	0.200	—	—
4991-R	Ground	2461	0.220	—	—
4991-R	As Cast	2300**	0.196	39,350	228
4023-L	Ground	2932	0.244	—	—
4023-L	As Cast	2749	0.232	52,880	235
4087-L	Ground	2777	0.248	42,260	235
4087-L	As Cast	2290	0.192	41,380	228
4088-L	Ground	2811	0.276	43,090	228
4088-L	As Cast	2596	0.236	41,630	228
4089-L	Ground	2950	0.276	44,380	235
4089-L	As Cast	2155**	0.176	42,420	235
4090-L	Ground	3333**	0.268	49,140	255
4090-L	As Cast	3065	0.236	49,150	255
4091-L	Ground	2634**	0.200	56,760	262
4091-L	As Cast	3264	0.264	54,500	262

*All test bars were cast 21 in. long and broken on supports 18 in. apart. All transverse loads were corrected to actual diameter of test bars. The deflection has not been corrected as the writer was unable to locate any correction factors at the present time.

**Flawed Bar.

Table 4
CHEMICAL ANALYSES

Lab. No.	Si %	S %	Mn %	P %	T.C. %	Ni %	Cr %	Cu %	Mo %
4886-R	1.74	0.080	0.39	—	3.44	1.56	0.70	—	—
4991-R	1.62	0.067	0.38	0.52	3.42	—	0.26	0.98	0.32
4023-L	2.08	0.116	0.64	0.19	3.10	—	—	1.41	0.67
4087-L	1.68	0.057	0.39	0.43	3.37	—	—	1.51	0.52
4088-L	1.68	0.057	0.39	0.43	3.37	0.54	—	—	0.57
4089-L	1.68	0.057	0.39	0.43	3.37	0.62	0.36	—	0.51
4090-L	1.77	0.146	0.63	0.18	3.04	—	—	1.17	0.57
4091-L	1.77	0.146	0.63	0.18	3.04	0.52	—	1.21	0.61

MR. MACPHERRAN: In replying to Mr. Green, I wish to say that we do not increase the bed for high test iron, but use the same coke as normally. We do not weigh the air for the cupola and cannot give the weight used. We have for some months used a lower bed of coke, in fact, going to 2100 pounds of coke. The iron is hot and the carbon a little lower. It is perhaps not quite as safe as to use the 2300 pounds of coke per charge.

Our method of operation graphitizes both in the cupola and ladle. We find this sufficient inoculation for high test iron. While we believe that the amount, size and type of non-metallic impurities are important factors, also we believe that a fine graphite formation is best. I would point out that we have avoided referring to any theories in this paper and would not care to start a discussion on same.

MEMBER: Do you tap out or run continuously?

MR. MACPHERRAN: We make short taps. We run all afternoon and have poured castings weighing as high as 57 tons. We make two taps for a 3,000 pound ladle from a 54-inch cupola. We think that when the iron stays in the cupola too long, it is apt to pick up more carbon, so we believe in short taps.

MEMBER: What size castings do you pour? What are your cross-sections?

MR. MACPHERRAN: Anything from $\frac{1}{2}$ -in. to something over 10-in. We hardly ever go under $\frac{1}{2}$ -in. sections as they are hard to machine. For some parts in crusher castings we go as high as 8 to 10-in. sections.

MEMBER: Did you ever take a bar out of a 10-in. casting?

MR. MACPHERRAN: We took a test bar out of an 8-in. hub. That broke at somewhere around 29,000. The iron is not as strong in a 10-in. section as it is in a 2-in. section.

MEMBER: What is the tendency to shrink in the heavy sections?

MR. MACPHERRAN: We never get any internal shrinkage. There is too short a freezing range. The iron does not have time to shrink. We cannot feed with a stirring rod, but must use a riser. If we try to go to churning, we are going to get into trouble. One must have a large riser and feed by gravity.

MEMBER: I have tried for quite a while to operate along the line Mr. MacPherran suggests, taking short taps out of the cupola. Our trouble has been with our first charge off the bed, trying to get low total carbon. The carbon would be higher than it would in the third or fourth.

MR. MACPHERRAN: Our first ladle is higher carbon than the second ladle.

MEMBER: For the first three or four taps, my total carbon would be higher.

MR. MACPHERRAN: As a rule, if you analyze each 3,000-lb. ladle that comes out, you will find the first higher in total carbon than the third. The first 3,000-lb. ladle is very often over 3 per cent. The third 3,000-lb. ladle never is. We get about 2.85 there and, in the long run, we will get as low as 2.65. We use a 54-in. cupola for small work and a 72-in. for large work.

MEMBER: The lowest total carbon I have obtained was 3 per cent. It would run low for awhile and then go up around 3.25, 3.30 and 3.40.

MR. MACPHERRAN: Maybe you are using too much coke. We use 3,000 lb. of iron in a 54-in. cupola and about 325 lb. of coke between charges.

MEMBER: I am using a 40-in. coke bed above the tuyeres and in between, every other iron charge, I put in 150 lb. of coke and the other coke charges are 100 lb.

MR. MACPHERRAN: That, I believe, explains why the carbon is irregular. It pays to keep the coke as nearly even as you can, because you are melting over 80 per cent steel.

MEMBER: In this cupola, my air is not coming through as it should; I am only melting $4\frac{1}{2}$ tons per hour in a No. 4 cupola. I should melt up to 6 tons per hour. That is a 40-in.

MR. MACPHERRAN: We melt about 9 tons per hour in a 54-in. cupola, but we purposely do not melt fast. We like a soft blast. We use about a 6-oz. blast in this 54-in. cupola which means about 9 tons of iron melted per hour.

MEMBER: I have 6 oz. on mine. If I cut down the coke, my iron does not come as hot as I would like to have it.

MR. MACPHERRAN: We get the iron very hot. Ours comes out above 2600 deg. F. always and we try to pour at 2500 deg. F., or better, that is, of course, on an ordinary sized ladle. If you are pouring a big casting, weighing say 30 or 40 tons, it takes longer to fill the ladle and you are bound to get the iron colder. On the other hand, of course, the section is thicker and you can use colder iron. It is really quite hard to take an hour and one-half's run from a cupola and keep it always above 2500 deg. F. But last month we poured a 50-ton casting, and poured it at a little over 2500 deg. That is about as hot as we can keep it. On a small ladle of 3,000 or 4,000 lb. we always tap above 2600 deg. The iron should never be below 2500 deg. when you go to pour it. High-test iron must be poured hot because the carbon is low and the phosphorus is low. It is almost all steel and the phosphorus is bound to be about 0.08 per cent.

J. A. BOWERS²: Mr. MacPherran, do you have a particular reason for adding your silicon and manganese to the ladle rather than in the cupola?

MR. MACPHERRAN: We do both. We put in ferro-silicon in the cupola and put a small amount of ferro-silicon into the ladle. If one wants to keep the iron thoroughly deoxidized, an addition of a little ferro-manganese-silicon is a very good thing in the ladle. We put in about 3 pounds of ferro-manganese-silicon per thousand pounds of iron, adding it in the spout. This iron is very easily oxidized. One should use short gates if possible, and keep the iron out of contact with the air all you can. Fill the mold fast. The deoxidizing power of carbon is low. We keep the manganese about 0.8 or 0.9 per cent, also. But a short gate is almost essential.

² American Cast Iron Pipe Co., Birmingham, Ala.

A. E. HAGEBOECK¹: Mr. MacPherran, can you tell why you get that reduction in tensile strength in the tests from bars poured after a 14-min. interval?

MR. MACPHERRAN: The tensile strength of the iron sometimes drops 15,000 lbs. per square inch between the first and the last iron from the same ladle. It is simply a fact that you have to pour your small ladles fast or else lose a great deal of strength. I would not want to furnish any theory for it. I am very short on theories.

¹ Frank Foundries, Moline, Ill.

Production of Some Iron Castings for Steel Works*

By J. ROXBURGH**, SHEFFIELD, ENGLAND

Abstract

In this paper the author gives detailed explanations of the problems encountered in the production of some of the larger castings for steel works, especially ingot molds, anvil blocks and cylinders. In discussing ingot molds, he emphasizes that the quality of these castings is measured by the number of ingots they will produce. The factors encountered in conditions of service are quite thoroughly explained. Composition of the metal is stated to be dependent on remelting requirements, and the composition from the standpoint of graphite and combined carbon, silicon and manganese is stressed. Types of iron used are described. The author then gives a detailed description of the manufacture of a 60-ton ingot mold, which is made by loam molding. Manufacture and composition of representative anvil blocks, cylinders and liners are described and illustrated.

1. Many complete individual units comprise what is referred to generally as a steel works plant and each of these units has its own special features and peculiarities of design and manufacture, according to the expert ideas of the manufacturer or user or both. Great strides have been made in the technique associated with the steel works and the manufacturer of the plant has improved his product to cope with modern demands.

2. The author is connected with a company, founded in the 18th century, whose chief manufactures are rolling mill plant, continuous and semi-continuous, hydraulic plant and forging presses as well as other steel works plant. Although the company has separate steel, roll and iron foundries, the author proposes to confine

* Official Exchange Paper presented on behalf of the Institute of British Foundrymen.

** Manager of Foundry and Pattern Shop, Davy Bros., Ltd., and President, Sheffield Branch, Institute of British Foundrymen.

his attention solely to the iron foundry, which is modern and up to date, having been built only 12 years ago. The iron foundry supplies castings to outside customers, as well as supplying the needs of the company's own engineering shops.

3. In surveying the requirements of steel works plant, as regards iron castings, it is of interest to record that, in England, a considerable quantity of the castings continue to be made in plain and alloy cast iron with and without steel additions to the mix, although there are many instances where steel castings are essential to cope with the heavy duty they have to perform. The author's foundry is capable of dealing with castings from a few pounds in weight up to 60 tons and, in addition to the castings for rolling mills, cylinders, rams and liners of all descriptions, anvil blocks, ingot molds and accessories, slag pans, etc., are manufactured. A paper such as this, cannot deal with all these types of castings, so the author has selected certain definite castings for more detailed consideration.

4. After perusing literature connected with the iron and steel industries, it is disappointing to find that there has been very little matter published on the subject of ingot molds from the manufacturer's standpoint, with the exception perhaps of papers contributed by Blakiston¹ and Ballantine within the past two years.

5. Due recognition, however, must be given to the amount of investigational work carried out by the users of ingot molds and it was only as recent as last year that Swinden and Bolsover² published an excellent paper on the subject from that angle, while the work of the Heterogeneity of Steel Ingots Committee of the Iron and Steel Institute is well known and authoritative. They are all to be congratulated on their efforts in this direction as their work is undoubtedly of distinct interest to the trade and a desire for greater co-operation between the user and manufacturer which is hoped will eventually lead to concrete developments seems to be indicated.

AN INGOT MOLD PRIMARILY A PERMANENT MOLD

6. As is probably well known, an ingot mold is primarily a permanent mold, supplied as a tool to the steelmaker. Into this mold, the latter teems molten steel either through the bottom or

¹ Blakiston, J., "Ingot Molds, Bottoms and Slag Ladles," *FOUNDRY TRADE JNL.*, vol. 52, Feb. 28, 1935, pp. 153-154 and Mar. 7, pp. 175-176.

² "Some Notes on Ingot Molds," *PROCEEDINGS, Inst. of British Foundrymen*, vol. 28, 1934-35, pp. 192-248.

from the top and when solid gives him a steel ingot of a desired shape and weight.

Designed to Meet Requirements

7. The steelmaker therefore designs the tool to meet his requirements as regards size, cooling rate of ingot, shape, solidity and soundness of ingot cast therein. Whether the mold be square, rectangular, slab, round, octagonal or duodecagonal, he determines the camber on the wall, the thickness of the walls, the radius at the corners, the capacity of the mold and any necessary lifting arrangements.

8. Ingot molds are made in this country varying in weight from a few pounds, up to 150 tons, embracing many shapes and sizes, the section of metal varying from say 2 in. up to 24 in.

QUALITY OF INGOT MOLD MEASURED BY LIFE

9. Naturally, the quality of an ingot mold can only be measured by the amount of service it gives to the steelmaker and so it is obvious, that the way to assess this is by counting the number of ingots that are made from the particular ingot mold or, as commonly referred to, the number of "heats" or "lives." It is of interest to the manufacturer to know that the steelmaker keeps accurate records of the life of the castings. But how often is this information available to the manufacturer except when some particular mold has failed prematurely and, in consequence, a complaint is registered? On the other hand, if he receives no news at all, he is at liberty to assume that, at least, the castings he has supplied are giving as good service to his customer as are his competitors'.

CONDITIONS OF SERVICE FOR INGOT MOLDS

10. Before attempting to manufacture any type of casting, the conditions of service that the casting has to withstand, must be thoroughly understood. The method of procedure in the steel melting shops will be considered briefly, although there are bound to be different methods prevailing in different firms.

11. Some ingot molds are coated on the inside surfaces with one of several types of facing material before being teemed into, while others, the author understands, are used in the condition as received and, it is presumed, some attempt, whether done in a scientific manner or not, is made to preheat the casting. When the

molten steel is run into the mold, the inner surfaces of the latter heat up very rapidly, which, in itself is a shock to the casting.

12. Time elapses for the passage of the heat through the walls and so the casting is unequally heated until such time as greater uniformity is reached, and thus the casting has to withstand this further attack upon it. Incidentally, it may be noted steel melts at 2730° F. and a hematite iron probably round about 2100° F.

13. When the ingot is solid and withdrawn, the mold is allowed to cool slowly or otherwise, according to practice. The particular mold may continue to be used regularly until its useful life is over or, on the other hand, its use may be intermittent. In any case, it is obvious that the casting has to withstand a series of expansions and contractions during the course of its life.

14. Another important feature is that the steel ingot produced must be sound, flat and smooth on all its surfaces and must be able to leave the mold without difficulty. The manufacturer of the ingot mold must, therefore, give very careful attention to the actual molding of the casting and the question of the most suitable metal to meet the service conditions. Then he has to rely on the care exercised by the steelmaker in the treatment of his casting.

15. Those steelmakers, who are responsible within their own organization for the manufacture of ingot molds for their own use, are naturally at an advantage. They can keep faithful records of the details of manufacture as well as of the ultimate service rendered by the castings. The jobbing iron founder, who supplies ingot molds to the steelmakers, can certainly standardize manufacture in his own foundry but is dependent on the steelmaker for any information as to useful life obtained. He probably feels that, if he were to supply a special experimental mold to the steelmaker, it would seriously interfere with the repetition and continuity of the latter's daily program.

16. It would appear, also, that each individual steelmaker has his own idea of design of ingot mold, of treatment before, during and after usage. There is also, the question of different types of steel and their effect upon the life of molds and so, at times, it is rather confusing to the foundryman when one mold of a certain capacity gives satisfaction to one steelmaker, while another mold of similar capacity, used in some other steelworks, has not given the same performance.

METALLURGICAL ASPECTS

17. Having dealt with the treatment meted out to the castings in the steel melting shops, the metallurgical aspect of the castings must be considered in detail. It would seem that there are many divergent opinions as to the most suitable metal for an ingot mold and research is still proceeding. Swinden, as a result of experience, dismisses the alloy iron mold, favors high silicon (1.9 per cent) and fairly low manganese (0.6 per cent) and is commencing investigation on the higher manganese irons (1.75 per cent). Blakiston, however, adheres to a silicon of 1.8 per cent and manganese up to 1.2 per cent. They both advocate low sulphur and phosphorus although mentioning German molds containing 0.2 per cent phosphorus. Swinden can see little benefit from steel additions, while Blakiston uses up to 6 per cent steel scrap in his mixtures and specifies above 3.5 per cent total carbon in his iron.

Composition Dependent on Remelt Conditions

18. To a certain extent, the mold manufacturer is in the hands of the steelmaker, as far as the metallurgy of the iron used is concerned as, in many instances, the mold, after its useful life, is melted up in the steel furnaces. For acid steel, this means that the material should contain 0.07 per cent sulphur and 0.07 per cent phosphorus as a maximum, although lower sulphur contents can be obtained, despite the fact that metal melted under cupola conditions picks up 0.03 per cent sulphur.

19. Be that as it may, the conditions of service of the ingot mold put definite limitations on the structure to be aimed at in the casting. As previously stated, the mold is subject to a series of expansions and contractions in the course of its life. It is, therefore, deduced that, under these very special conditions, a power of elasticity and recovery be imparted to the casting, that the metal should contain a low combined carbon and have a large percentage of free graphite. From this, then, a high total carbon content and sufficient silicon to precipitate a large proportion as free graphite, is indicated.

Large Graphite and Oxidation

20. That meets the situation as far as standing up physically to its work, but there is the chemical aspect to consider. These large graphite flakes, unfortunately, form inroads along which oxidation can and does take place leading eventually to failure of the

mold surfaces and the familiar *crocodiling* effect. The microstructure of an iron as previously described shows a large percentage of ferrite and graphite and a small percentage of pearlite, all constituents having their respective expansions, which, in itself, under conditions of service, causes breakdown of the surfaces. All these factors lead to formation of oxides and finally fissures.

Combined Carbon and Graphite

21. In endeavoring to obtain a structure in the casting, it would seem that it is a question of, first, how high can one go with the combined carbon content and, second, to what degree of fineness can one take the graphite present.

22. The author recalls some ingot molds he once made containing 3.0 per cent total carbon, which cracked after only two heats and were beyond use. He decided that the low total carbon had caused the casting to be too rigid and lacking in ability to withstand the heating and cooling to which it was subjected. His experience on chills for chilled rolls bears this out too, as chills made for experiment, containing 3 per cent total carbon, cracked early in life and were rendered useless.

23. If a high total carbon content is, therefore, advantageous, how can a finer graphitic structure be obtained, together with a low combined carbon in the resultant casting? It is recognized that when ferrosilicon is added to a material such as steel scrap where all the carbon is in the combined form, the resultant graphite produced is in a fine state of dispersion. Is there an iron available, a white iron, containing a high total carbon and a low sulphur and phosphorus? Would it be possible for example, to experiment with a Swedish white iron, containing approximately 3.5 to 4 per cent total carbon, 0.3 per cent silicon, 0.5 per cent manganese, 0.03 per cent sulphur and phosphorus and add sufficient ferrosilicon to precipitate a large percentage of the carbon as graphite? Also would ferromanganese have to be added to adjust the manganese content? If this attempt proves that the structure is too close, then make various additions of hematite to increase gradually the size of the graphite. By adding ferrosilicon to the Swedish white iron, probably some of the carbon would be thrown out of solution but the total carbon would still be high enough. Other possibilities spring to mind such as the consideration of an inoculated iron or the use of another type of melting medium, with higher temperatures and lesser contamination.

Manganese

24. With regard to the manganese content, the writer once supplied some small ingot molds to a steelmaker, some containing 1.5 per cent, some 1.75 per cent and some 2.0 per cent manganese. It was reported to him that those containing 1.75 per cent manganese had given an enhanced life and that 1.75 per cent manganese seemed to be an optimum content. It is recognized that manganese above 1 per cent imparts heat resisting properties to the metal, under certain conditions, and that manganese, of that percentage, favors the retention of carbon in the combined form.

25. As far as the author's own experience goes, and this is over a considerable number of years, he finds that on large molds a mixture of approximately 25 per cent hematite scrap, 30 per cent west coast hematite (2.5 to 2.75 per cent silicon and 0.5 per cent manganese) and 45 per cent east coast hematite (1 to 1.25 per cent silicon and 1.0 per cent manganese) has given satisfactory results, the ultimate analysis being above 3.6 per cent total carbon, 1.6 to 1.8 per cent silicon, 0.5 to 0.7 per cent manganese, 0.07 per cent sulphur max. and 0.07 per cent phosphorus max.

26. The author supposes that it is only natural that each manufacturer of ingot molds adheres to his favorite brand or brands of hematite pig iron, and, undoubtedly, each brand possesses certain definite properties according to the ore from which it was smelted and to the conditions under which it was manufactured in the blast furnace. It would be interesting to collect data, if it were possible, on this matter.

Foundry Treatment After Casting

27. Another point affecting the structure of an ingot mold is the treatment it receives in the foundry after casting, as regards the acceleration or prolongation of the cooling rate. The author makes a point of leaving his castings in the sand for a more or less definite period, according to their size, as he feels that the natural cooling and annealing effects thus obtained are advantageous to the ultimate service life of the casting. With larger molds the approximate procedure is to take 20 ton molds out of the sand in 2 to 3 weeks, 40 ton molds in 3 to 4 weeks and 60 ton molds in 4 to 5 weeks.

MANUFACTURE

28. So much for the metallurgical aspect of ingot molds and now to the actual manufacture. It has been obvious in the survey

thus far that, as far as the foundryman is concerned, his casting must be sound and accurate of dimensions, within foundry limits. The most important consideration is the inside of the ingot mold, which must follow the contour laid down by the designer, must be free from defects of any consequence, and must be flat, smooth and level on all inside surfaces. It is obvious that it would be no use supplying a mold with a wavy appearance or one with any holes or indentations inside as this would interfere with the contraction of the ingot or would serve as a weak spot for the steel to attack. Again, any chipping inside should be kept within bounds, as the destruction of the cast face is detrimental to its life.

Sand

29. Naturally, the methods of manufacture of ingot molds vary from foundry to foundry and each possesses its own technique as regards the type of sand used, the method of making the mold, the running of the casting, the casting temperature and the details of the tackle employed. In the first place, the question of a suitable sand for the core is of absolute importance and, again, the technique evolved often depends on the locality where the foundry is situated as, for economy, the possibilities of the nearest supply of sand are usually explored.

30. For smaller molds, the sand must be capable of being sufficiently rammed and refractory enough to resist the pressure and temperature of metal and yet of the correct permeability to avoid scabbing. For these purposes, some people prefer a coarse, uniform-grained sand, strong in bond, while other prefer a very weak bonded sand. Some cores are jolt rammed, some hand rammed and, in the latest development, Ballantine rams with sand both the molds and cores for ingot molds up to 30 tons in weight. For large molds, the author's practice is to build both mold and core with Sheffield steel molders composition loam, a material of high refractoriness and able to withstand the pressure of large masses of metal.

Method for Large Ingot Mold

31. The author can only describe the methods and technique in his own foundry, which perhaps may not be the best methods, although he claims consistency in his results.

32. The demands made upon the foundry in the case of a 60 ton mold are similar to those for a small mold in regard to finish and accuracy of dimensions of same but, naturally, a 60-ton

mold presents a much more responsible problem to the foundryman.

33. *Pattern:* It is customary for the mold and the core to be built up as a loam job from a skeleton pattern and core frame. This 60-ton casting is octagonal in shape, both outside and inside, (Fig. 1). The outside mold is constructed in a tanked pit, 15 ft. dia. by 14 ft. deep. The core has, in this case, 60-tons of metal around it and still has to leave the casting smooth, flat and free from defects of any consequence.

34. *The Mold:* The bottom of the pit is rammed with sand and a bottom plate with 8 lugs placed on this bed. A layer of bricks is laid thereon, interspersed with ashes, and the core print then bedded in. Next a level seating is struck on which the skeleton pattern is erected. This pattern consists of a top and bottom frame,

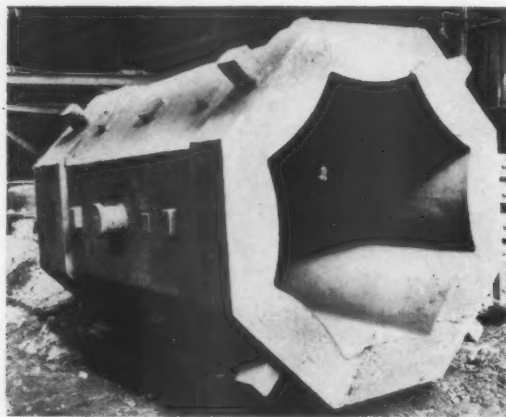


FIG. 1—OCTAGONAL INGOT MOLD WEIGHING 60-TONS.

carried with wooden "props". Bricking, (the bricks used being soft and porous "clamps") is carried out to the top, with lugs, trunnions and ingates built in their respective positions. It is usual practice to build up the mold in substantial building rings 2 in. thick, the space between the outside of the bricks and the inside of the rings being rammed with sand.

35. The bricks are faced with about 1 in. of loam, which consists essentially of Sheffield *steel molders composition*, the main components of which are old crucible pots and firebricks. After the mold has been completely struck-up, a straight edge strickle

guided by runners on the top and bottom frames is used. The skeleton pattern then is dismantled and withdrawn.

36. *Finish:* The molder now proceeds to finish the mold, then blacks it in the green state, the refractory facing used being mixed as follows: 225 lb. of best quality high carbon blacking is mixed with thin claywash to a thick paste and 7-lb. of core gum, made with hot water is added. This paste is left to ferment for 48 hrs. and then wet down with thin claywash to the desired consistency.

37. Drying the mold is affected by means of a coke grid fire. Then the top plate, provided with holes for the runners and two

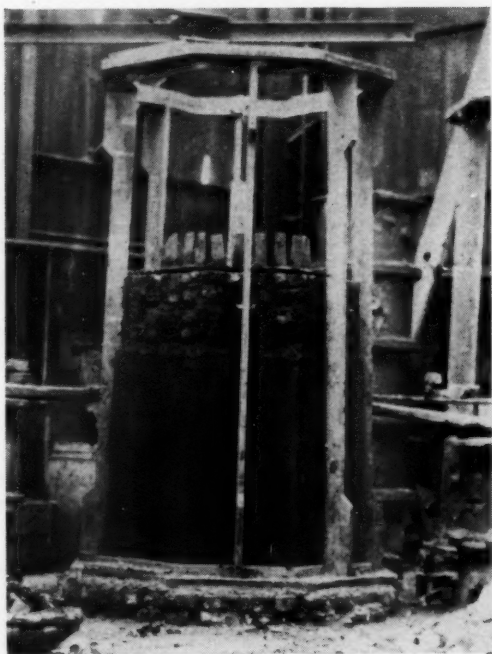


FIG. 2—METHOD OF MAKING INGOT MOLD CORE.

risers is struck up with composition loam and put on the stove to dry.

The Core

38. The more important job is the making of the core. A

bottom core plate with four staples, accurately cast from a pattern, and a corresponding top wooden frame, supported at the correct height and relative to the bottom core plate, is provided and a straight edge strickle is run on the outside of these two frames. (Fig. 2.)

39. It is a difficult problem, however, to ensure a strong core and one, at the same time, able to take care of the contraction stresses. With this in view, the core is built up with bricks and loam. Grids, with dabbers cast on, are placed at 8 in. vertical intervals, which materially strengthen the core. Loam bricks of special shape and size are inserted at the corners and centre of the flats of the core, with soft bricks in the intervening spaces, a procedure essential to ensure success.

40. Between the loam bricks at the corners, the space is rammed with core sand, so that pricking can be done through to the centre of the core for venting purposes. Again to prevent any irregular squeezing of the core, which would make it impossible to obtain the smooth surface insisted upon, the bricking should be carried to the dabbers of the grid.

41. The core is faced with 1 in. of steel molders composition loam, finished, air dried and blacked with similar blacking to that previously described while green. The core is then lifted from the staples on the lugs at the bottom core plate onto the stove for drying.

42. When closing, the core is accurately located in the print in the mold, and the inside of the core rammed up with black sand. Vents are brought up to the top. Special attention should be paid to this point, as the vent is made by ramming long rods inside the core and withdrawing them to provide outlets for the escape of gases.

43. The top plate is next located and the core stamped so as to avoid any metal gaining access to the inside of the core. It is then packed and securely bolted to the lugs at the top building ring, which has previously been bolted down to the bottom plate. As an extra precaution, black sand is rammed in the pit round the outside rings to a depth of 4 ft. The runner dishes and riser bushes are placed in their respective positions and weights put on the top plate.

Gating

44. Too great importance cannot be attached to the running

of such a casting and, in this case, three downgates are used, necessitating 3 ladles and 3 cranes. The 3 ladles are of 30-tons, 22-tons and 16-tons capacity respectively. The ingate from the 16-ton ladle, which is poured first into a spout runner, is placed 1 in. from the bottom of the mold. The ingate from the 22-ton ladle, second to be poured, has two ingates one of which enters 2 ft. higher than the ingate for the 16-ton ladle and the other, 7 in. above half way up. The ingate from the last ladle, the 30-ton, is placed half way up. In all cases, the downgate should be $5\frac{1}{2}$ in. diameter and the ingates $6 \times 2\frac{3}{4}$ in. to $5\frac{3}{4} \times 2\frac{1}{2}$ in. and set at a tangent to the mold so as to prevent the stream of metal directly impinging on the corners of the core and to impart a uniform swirling motion to the metal.

45. If this swirl is not maintained throughout the running, it will probably be found that some scum or dirt has been trapped against the core and so the higher level of ingate speeds up the flow of metal, which, before it reaches the latter ingate is tending to lag.

Risering and Heading

46. Incidentally, a 9-in. head is cast on the top end of the mold to ensure soundness after machining. There are two risers, also about 6-in. dia. which take approximately 2 hrs. to feed.

Possible Defects

47. Ingot mold castings are subjected, after fettling, to a very rigid inspection, when apparent defects are immediately brought to light. Occasionally, small holes are discovered, filled with sand, blacking or slag, or they may be clean holes. This points to dirty metal, bad running, scabbing or to the blacking being washed off if not sufficiently tight. Again, cold-lap marks may be evident due to dull metal. Incidentally, casting temperature is important. Usually, metal is melted at a high temperature and allowed to cool down to a definite temperature for casting.

48. Variation in dimensions across the flats is encountered and, with a large mold, this may reach $+\frac{3}{8}$ -in. This may be due in some degree to inaccuracies in molding, to the settling of the core and to lack of uniform contraction. At times a slight camber on the vertical faces inside the mold is discovered and this may be due to the contracting and squeezing.

49. Another defect, not so easy of explanation, is the occur-

rence of small blacking scabs in the corners of the inside of the ingot molds. Some, attribute it to casting temperature, some to method of application of blacking, by which several coatings of blacking exist so that the metal gets behind the top one. Others believe that, due to the squeeze in contraction, the corners get squeezed to a greater extent, which disturbs the blacking causing the metal to penetrate. Personally, the author finds that, with a properly dried core and the proper sand control, this defect is rare.

Possibilities

50. It will be realized that the subject of ingot molds is full of possibilities of research and discussion. Essentially, the steel-maker wants something better from the foundryman, who, however, without full knowledge of the service conditions, is at a serious disadvantage. It is, therefore, necessary for the steelmaker to standardize his practice in regard to ingot molds and then to acquaint the foundryman with full particulars so that the latter can deal with the matter scientifically.

ANVIL BLOCKS

51. It cannot for a moment be said that a 45-ton anvil block is a difficult job to mold, as far as skill in actual molding craft is concerned. At the same time, unless the correct procedure is adopted and suitable materials made used, dire results are certain to accrue.

Cores

52. In the block under consideration, there are six poppet and six cotter cores. The latter are 7 x 2 in. and extending 9-in. through the poppet cores. In addition, there are numerous other cores of varying shapes and sizes. (Fig. 3.)

53. At one time, it was permissible to reinforce such cores with cast iron casings $2\frac{1}{2}$ -in. thick. However it was found that, in actual service, these castings formed a weakness in the block, leading to its premature cracking. Today, these cores are made from a special refractory material without any superficial reinforcements and can be fettled out comparatively easily. With the use of pneumatic tools, it is possible for two fettlers to fettle such a block completely in 8 working days. On the behaviour of these sand cores, subjected to a high temperature and surrounded by a large mass of metal, depends, to a great extent, the success of the

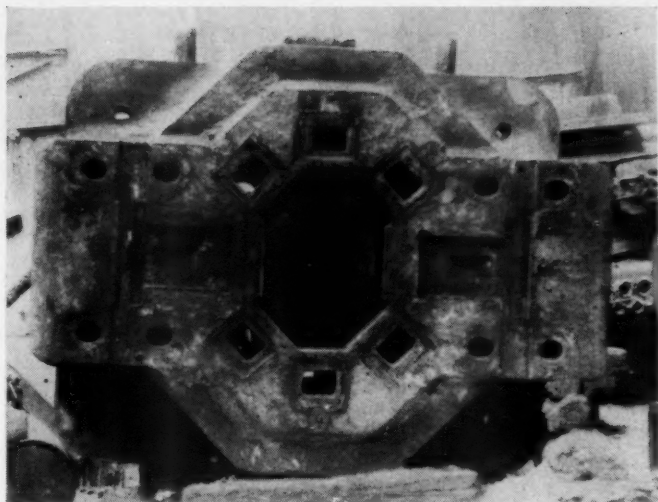


FIG. 3—LARGE 45-TON ANVIL BLOCK, SHOWING COTTER AND POPPET CORE HOLES.

job and it is gratifying to record that these anvil blocks have been made successfully over a long period.

Metal Allowance

54. Equally important, of course, is the metal used for such a block as well as the solidity and soundness of the casting. It is usual to allow 1-in. machining on the top side of the block and to place a 16-in. dia. riser right on the centre for feeding purposes, which takes 10 to 12 hrs.

Composition and Mixtures

55. Realising the service demanded of this block, it is obvious to the founder, that a high quality iron is required, although the engineer has designed a very heavy large-section casting to cope with the heavy duty. Today, usually, a definite analysis is specified to be worked to. A typical specification for such a casting is:

T.C.	Si.	Mn.	S.	P.
%	%	%	%	%
3 to 3.25	1 to 1.2	0.5 to 0.7	0.06 to 0.09	0.4 max.

56. The analysis of the metal, however, is not everything

and is merely a guide as the irons constituting the mixture and the conditions of melting are equally or more important.

57. With cupola melted metal, the author has used successfully a mixture consisting of 16 per cent steel rail ends, 20 per cent east coast hematite (1 to 1.25 per cent Si. and 1 per cent Mn.), 16 per cent cylinder iron, 16 per cent semi-steel scrap, and 32 per cent machinery scrap. This mixture on a recent cast, yielded the following analysis:

T. C.	Si.	Mn.	S.	P.
%	%	%	%	%
3.06	1.07	0.60	0.090	0.36

58. In his experience, the author has obtained 30 per cent of the total weight of iron required from the air furnace where, it is well known, a reduction of total carbon, silicon and manganese takes place and that no gain is registered in the sulphur content, all of which help to produce a refined iron.

59. For all low-silicon mixtures in his foundry, the author makes use of the chill test and, in the case of this block, a depth of chill of 1 to 1¼-in. is usually recorded. Probably a metal with a lower silicon content, and consequent greater chill depth on the test piece, would be considered more suitable for a casting of such a large mass of metal. However, the time for the collection of metal and the running of the casting has to be taken into consideration. The analysis previously stated is eminently suitable both from the point of view of structure and of "castability".

Pattern and Mold Buildup

60. The important features of the manufacture of the casting must be given attention. A full pattern is usually provided with the necessary coreboxes.

61. A bottom plate is bricked, and irons built in the brickwork at definite places to permit, at a later stage, bolting down the various cores. Core prints are bedded in and a coating of loam struck on. In all cases, therefore, prints are made bigger than the actual core size, and the cores are constructed with a foot piece to fill these corresponding prints. These feet provide a good foundation for the cores to stand upright and also help to keep the cores in position when the metal runs over them. The pattern is then put on this seating and bricked up to the joint. As an extra precaution, provision is made for bolting back those cores which fit into prints on the side of the mold.

62. Another important point to note particularly is the specially made top plate made with holes to correspond with the poppet cores thus to allow them to come through and to expand without hindrance and also for the vent to escape easily. When closing the bottom part of the mold, (Fig. 4), a wooden template supplied to center the poppet cores will be found extremely useful so that they will pass through the top plate when finally placed. The mold is built up in building rings 2 in. thick and top plate bolted down to the bottom plate.

Core Procedure Most Important

63. The manufacture of the cores is really the most important operation and the refractory used has for its chief constituent silica rock, which is mixed with "compo" and other ingredients and milled. Loose irons alone are used for reinforcing the poppet

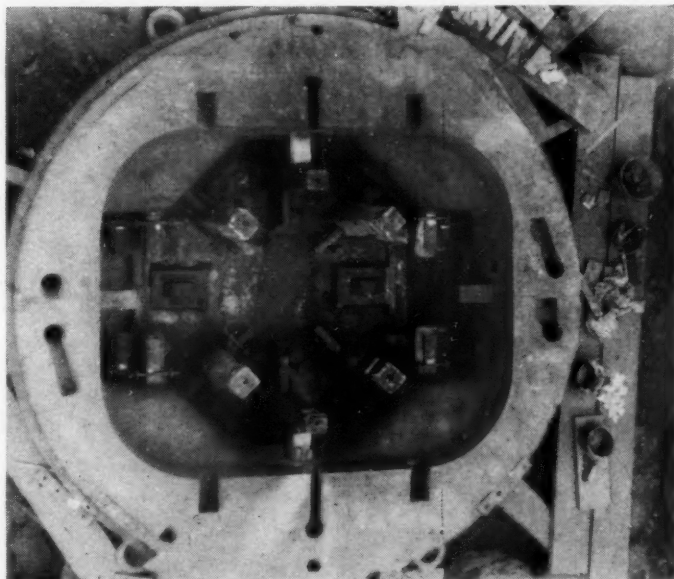


FIG. 4—LOOKING DOWN INTO THE MOLD SHOWING POPPET CORES IN PLACE.

and cotter cores and the latter, after drying and cooling, are painted, first with black paint and then finally silica paint. A very hard core indeed is obtained in this manner. Its refractoriness under load is excellent and no fritting takes place when the

metal comes in contact. These cores leave good surfaces when fettled out as this is essential as well as accuracy of dimensions. Due attention, therefore, must be paid to the refractory materials used and to the bolting of the cores in position in the mold so that they are not disturbed in any way.

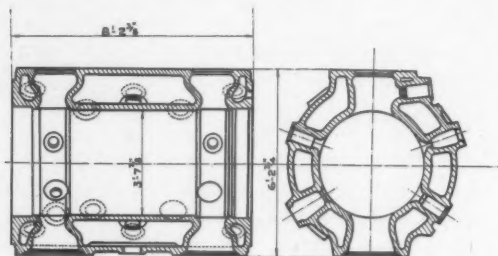


FIG. 5—DRAWING OF GAS ENGINE CYLINDER SHOWING MAIN DIMENSIONS.

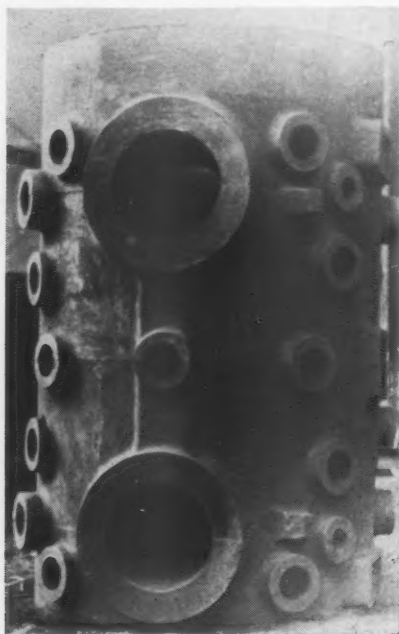


FIG. 6—GAS ENGINE CYLINDER CASTING.

64. The author has dealt with the precautions which must be observed in the manufacture of this 45-ton block, together with the metallurgical aspect, and, by paying strict attention to the details enumerated, such castings can be made successfully as a routine job.

GAS ENGINE CYLINDER PROCEDURE.

65. The gas engine cylinder illustrated weighs approximately $14\frac{1}{2}$ tons finished and the main dimensions are shown on Fig. 5. In preliminary consideration of this job, (Fig. 6), in respect to molding, there are three main parts: (1) the outside mold (2) the center core and (3) the jacket core.

66. It is necessary that each of these portions should consist of four parts, split at the same joints so that all the cores may be put in position during the closing operations. Regarding the leading off of the vent from the jacket core, where possible, advantage is taken of those cores cutting through on the outside of the mold and, as an extra precaution, six cores $2\frac{1}{2}$ -in dia. are taken off the top of the jacket core through the head and afterwards

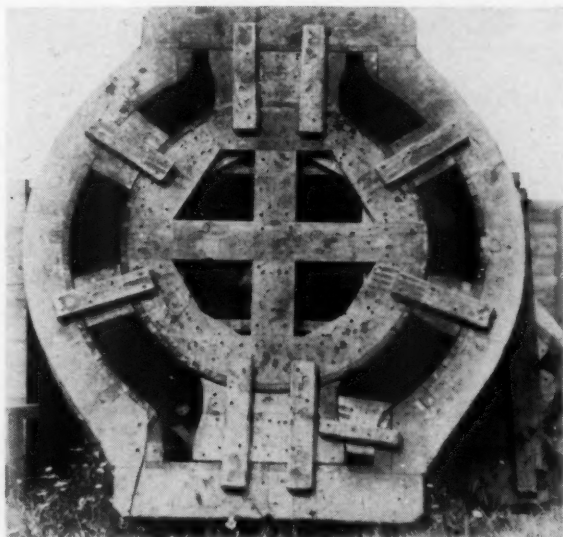


FIG. 7.—SEGMENT CORE BOX FOR JACKET CORE FOR GAS ENGINE CYLINDER.

plugged up. A 12-in head is incorporated on the top of the casting to ensure solidity.

Gating

67. The running is effected by two down-gates $2\frac{1}{2}$ -in dia., on opposite sides of the casting, with tangential ingates entering at the bottom. Nineteen tons of metal are required, equal amounts in each ladle. During pouring, when the metal has reached approximately half way, six top gates $2\frac{1}{4} \times \frac{5}{8}$ -in. are released down the bore only.

Pattern Tackle

68. The pattern tackle supplied consists of loam tackle, boards, loose chests, loose bosses for the outside and center core and two segment core boxes for the jacket core (Fig. 7).



FIG. 8—OUTSIDE OF MOLD FOR GAS ENGINE CYLINDER.

Outside Mold

69. The outside consists, as stated of four parts, each carried with a joint plant and one row of bricks only is built, spaces being left where necessary to take off the vents (Fig. 8). After closing,

cast iron rings are put round, the space between the brickwork and rings being filled up with black sand and ashes.

Cores

70. The jacket core is made with oil sand, sea sand being used with a proprietary oil compound. The core is made in four pieces, each core being reinforced with a cast iron grid. The joint of each core is made perfectly level and the whole core assembled before closing and rubbed where necessary to ensure accuracy and alignment (Fig. 9).

71. The center core is bricked up separate in four pieces, a cast iron plate carrying each part and prints are bedded in where required (Fig. 10).

72. When closing, the bottom tier of the outside mold is laid

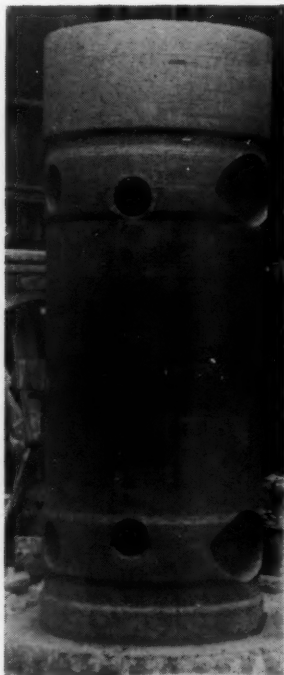
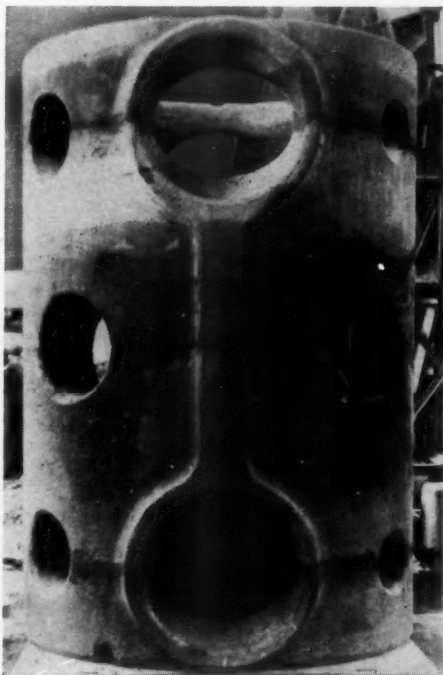


FIG. 9—(LEFT) ASSEMBLED JACKET CORE FOR GAS ENGINE CYLINDER.
FIG. 10—(RIGHT) GAS ENGINE CYLINDER CENTER CORE.

in the pit and the first layer of the center core located in the print. Four cast iron screwed studs are placed in the bottom of the mold and then the first piece of the jacket core is supported on these studs.

73. All the small cores are then placed in position (Fig. 11). Each tier of outside center core and jacket core is built up likewise and each time the small cores are located. As each segment of the jacket core is assembled, a level joint is ensured and stamped, and six vents, from the ashes, are led up to the six $2\frac{1}{2}$ -in. dia. cores at the top, in which pipes are inserted to lead off the vent. On the top of the jacket core, four cast iron screw studs are placed, packed to the core iron and eventually to the top plate to prevent lifting of the jacket core. The pouring of the casting is shown in Fig. 12.

The Metal

74. The mixture of the metal used for this casting is: remelt iron 16 per cent, mottled iron 16 per cent, cylinder iron 24 per

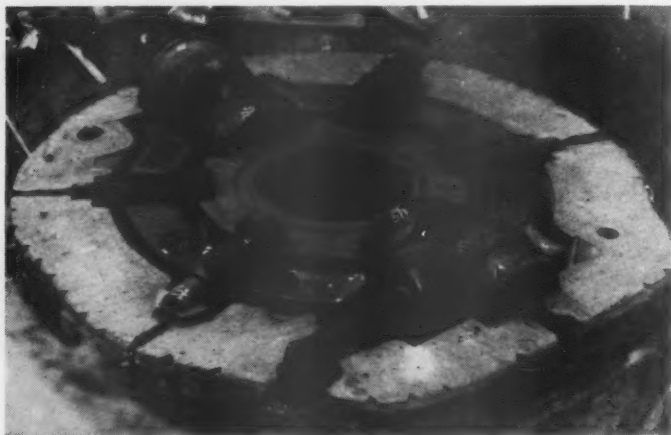


FIG. 11—SMALL CORES LOCATED IN PROPER POSITION IN GAS ENGINE CYLINDER MOLD.

cent, semi-steel scrap 20 per cent and cylinder scrap 24 per cent. A recent analysis showed:

T. C.	Si.	Mn.	S.	P.
%	%	%	%	%
3.06	0.98	0.48	0.090	0.32

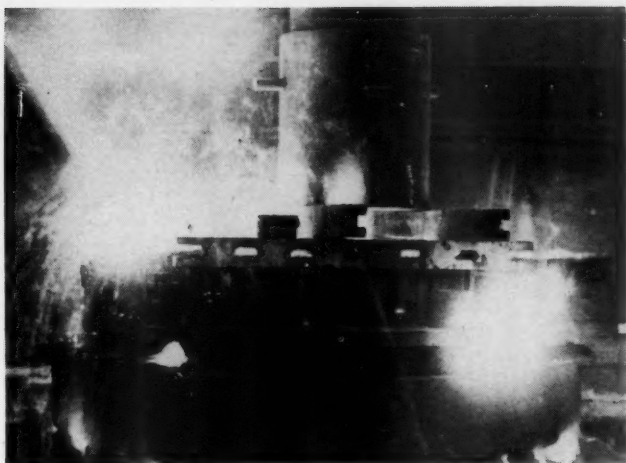


FIG. 12—POURING THE GAS ENGINE CYLINDER.

giving 1-in. on the chill test. The metal in the bore of the cylinder is $2\frac{1}{2}$ in. thick, when finished, and shows on machining a dense close material.

LINER FOR GAS ENGINE CYLINDER

75. The liner for a gas engine cylinder is 1 in. thick when machined, and $4\frac{1}{2}$ ft. long. A 12-in. head is cast on to ensure cleanliness and solidity. The outside is rammed upon from a wooden plug pattern and the core is struck up separately with a 7/16-in. metal allowance left all over for machining.

76. The method of running adopted is a down gate with a

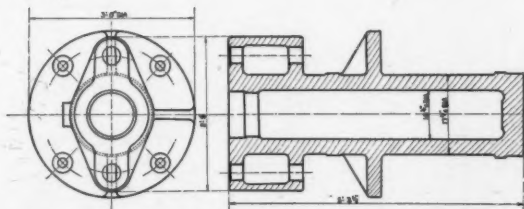


FIG. 13—DRAWING OF LOW PRESSURE INTENSIFIER CYLINDER.

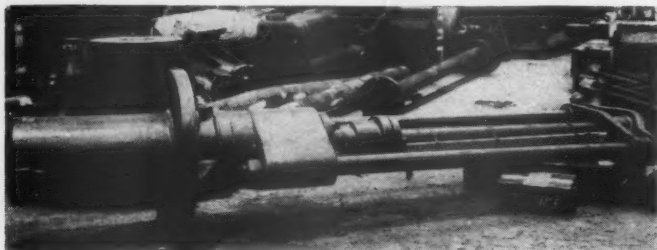


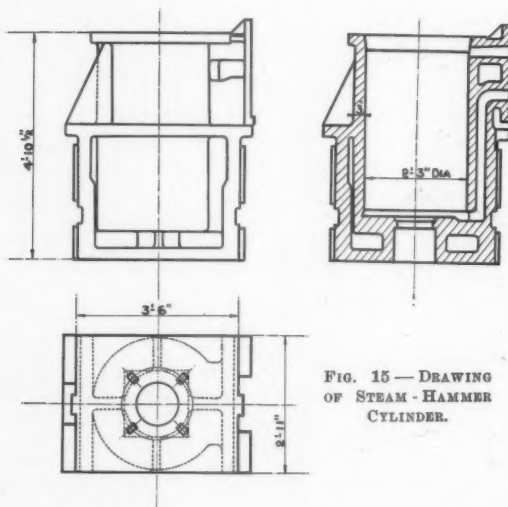
FIG. 14—INTENSIFIER CYLINDER CASTING ASSEMBLY.

tangential ingate entering at the bottom to form a cushion of metal before eight top gates $2 \times \frac{3}{8}$ -in. are released.

77. A similar analysis is aimed at as for the cylinder with the exception that the phosphorus is usually kept at 0.25 per cent.

INTENSIFIER CYLINDER

78. The intensifier cylinder is of the low pressure type, demanding a test pressure of one ton per sq. in. Here, again, the question of the metal is vitally important as well as the soundness of the casting. The walls of the cylinder, it will be noted are $3\frac{1}{4}$ in. thick (Figs. 13 and 14).

FIG. 15 — DRAWING
OF STEAM-HAMMER
CYLINDER.

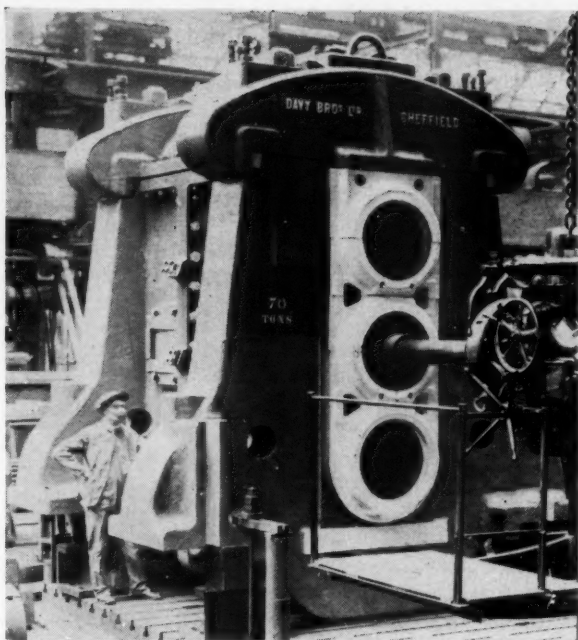


FIG. 16—PINION HOUSING, IN HALVES, AND HOUSING CAP. TOTAL WEIGHT, 70-TONS.

79. These cylinders are molded horizontally in suitable cylinder boxes made specially for the job. The mold is closed horizontally and the main core held in position with chaplets. It is then reared up vertically for casting. A 2-ft. head is incorporated on the closed end to insure solidity. These castings are run from the bottom with a tangential ingate to insure that the metal is given a spinning action.

80. For such castings, a close grained structure is essential and, with this in mind, low carbon, a low silicon and low phosphorus is aimed at in the metal. A suitable mixture is made with steel scrap, mottled iron, cylinder iron and cylinder scrap.

81. The chill test obtained on a recent cast was $1\frac{5}{8}$ -in. the analysis being:

T. C.	Si.	Mn.	S.	P.
%	%	%	%	%
2.92	0.74	0.5	0.092	0.20

OTHER TYPES OF CASTINGS

82. Many types of cylinders and rams are made in this foundry and an example is shown (Fig. 15) of a steam hammer cylinder containing port cores. Detailed attention must be paid to the molding, the methods and cleanliness of running, and to the metallurgical aspect in all cases to insure success.

83. An illustration is shown (Fig. 16) of a pinion housing, in halves, and a housing cap, the total weight being 70-tons. Such castings are usually bedded in the floor and a box part used for ramming the top. Good results have been obtained by admixing a small quantity of ganister with the sand used for the top part, to strengthen the sand.

84. A semi-steel mixture is invariably used to give an approximate analysis of:

T. C.	Si.	Mn.	S.	P.
%	%	%	%	%
3.25	1.20	0.6	0.08	0.4

this mixture consists of 20 per cent steel scrap, 20 per cent east coast hematite (1 to 1.25 per cen Si. and 1.0 per cent Mn.), 20 per cent semi-steel scrap, and 40 per cent machinery scrap.

85. A 50-in. roll-lathe bedplate, is 32 ft. long and weighs approximately 15 tons. The slides of course, are cast face downwards and must give good wearing surfaces. A semi-steel mixture is used for this casting. It is interesting to record that $\frac{3}{4}$ -in. camber was required on this bedplate casting.

SMALL CASTINGS

86. A few examples of small castings, which require special attention to insure sound, clean castings are shown in Fig. 17. The illustration includes valve liners, drop valves, lifting valves, valve bodies and bevel gear housing. Considering the valve liner, for instance, with the rectangular ports. This casting is molded horizontally and cast vertically with a runner through the center of the core and a strainer core is used in the bush, thus insuring freedom from dirt in the casting. Naturally, in all cases, the metal must be cast at a high temperature and, where the castings require machining all over, special methods of running are employed. Nickel, chromium and molybdenum either separately or together are incorporated in certain alloy cast iron mixtures for castings demanding special service conditions.

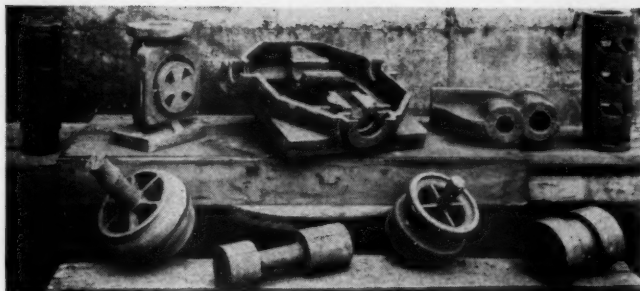


FIG. 17—A GROUP OF SMALL CASTINGS THAT REQUIRE SPECIAL ATTENTION TO INSURE SOUNDNESS AND CLEANLINESS.

ACKNOWLEDGMENT

87. In conclusion, the author wishes to take this opportunity publicly of thanking his Directors and Mr. W. Reid, general manager, Davy Bros. Ltd., Sheffield, for permission to publish this paper and would convey most hearty and cordial greeting to the members of the American Foundrymen's Association.

DISCUSSION

Presiding, J. W. BOLTON, Metallurgist, Lunkenheimer Co., Cincinnati, Ohio.

The paper by Mr. Roxburgh was summarized by J. W. Kleier, assistant superintendent of foundries, Allis-Chalmers Mfg. Co., Milwaukee, Wis.

CHAIRMAN BOLTON: The next paper that will be presented is an international exchange paper of the Institute of British Foundrymen. It is entitled "Some Steel Works Castings," and was prepared by Mr. J. Roxburgh of Davy Bros., Ltd., Sheffield, England. It will be presented by Mr. Kleier of the Allis-Chalmers Company. Mr. Kleier.

... Mr. Kleier abstracted the paper ...

J. S. VANICK: This type of paper, I believe is one that we could very well afford to indulge in more liberally for the discussion raising features that it would provoke among foundrymen who are quite well submerged in their work. In the course of the presentation of the paper I was unable to bore into the paper but I find on page 6, for instance, referring to ingot molds, that Mr. Roxburgh makes the very pointed suggestion that a good mold iron might be made from a Swedish iron very low in silicon, (0.3 per cent.,) and 3.5 to 4 per cent carbon, and that you might further add graphitizers to this to bring it into proper condition.

And then, down about two-thirds of the way in the paragraph, he says "Also ferro-manganese would have to be added to adjust the manganese content?"

Those points are quite logical in their substance and we have been doing some work in that direction. Some day we may find out whether this makes a good ingot mold or not.

Dr. MacKenzie, sometime ago, working with irons of this Swedish type, sent us some samples which we subjected to growth tests which showed that they possessed very desirable properties. They also seemed to have a good thermal conductivity, which is not necessarily characteristic of all of these irons, and a low expansivity. The very high carbon content seemed to be desirable in ingot mold irons and we have our own experience with castings similar to ingot molds, which would probably be better described by some of the foundrymen who make them. Our castings are settling pots, each weighing five tons, and they have about a four-inch-thick wall. The base composition is somewhat different from that registered for the British practice. They are made essentially of nothing but Bessemer pig, which finishes in the casting about 3.5 per cent carbon, silicon about 1.3 per cent or within 10 points either way, a normal manganese of about 0.60 to 0.80, very low sulphur, under .05, usually as low as .06—that would be obtained by desulphuring and phosphorus also extremely low. Small additions of alloys are occasionally used. They are not the carbide-forming kind. And I see that Mr. Roxburgh quite pointedly raises that question (p. 362), suggesting that manganese above 1 per cent imparts heat-resisting properties to the metal, "under certain conditions," and that manganese, of that percentage, favors the retention of carbon in the combined form. Now, back two pages, he also brings out the point that it is desirable not to have a high combined carbon in these ingot mold irons for steel ingots, and that seems to agree with our experience.

One other practical feature (refer to bottom of page 362, Foundry Treatment) these 5-ton pot castings of ours are specified to stay in the mold for four days and there has been enough work done to prove that that is a very desirable thing. So that the conditions which Mr. Roxburgh mentions here of leaving 20-ton molds in the sand for two-thirds of a week, 40-ton molds for three-quarters of a week, and 60-ton molds for four-fifths of a week would, in our opinion, be just a little bit fast.

CHAIRMAN BOLTON: Years ago I was in the heavy machine tool game. The time of leaving the casting in the mold given by Mr. Roxburgh, seems to be rather brief when you consider these sixty and seventy-ton castings. It seems to be more rapid removal from the mold than is customary in American practice. Probably some of you here are from foundries that make heavy castings, not necessarily exactly the same types as we have here, but we would be very glad to have you discuss this paper.

MR. KLEIER: I wish to state that our practice at Allis-Chalmers is that we leave any casting that has any tonnage for six days and on the third day just strip part of it, perhaps the center core. At the end of six days, we shake it out and let it rest for two more days before we chip it or take it out. Six days is the general period which is run on all heavy work. These are castings that run from 20 tons to 70 or 80 tons.

¹ Metallurgist, International Nickel Co., New York, N. Y.

Seemingly, we have fairly good success, without any trouble such as cracking. The temperature of our casting when it comes out of the mold is such that one is not able to hold his bare hand on it for more than two or three seconds.

In the winter months we add a day to it because of the coldness in the plant. We have just made our own practice, figuring that a day longer does not harm anything and we may save our casting. That is the procedure that we follow with our large castings.

R. F. HARRINGTON²: We make very few castings of anywhere near the dimensions mentioned. A casting two inches thick and 30 or 40 inches in diameter, 40 or 50 inches long, would probably stay in the sand about 24 hours. A casting three inches thick I think would possibly stay in there for 24 to 48 hours. We make nothing that is comparable to the size mentioned by Mr. Roxburgh.

CHAIRMAN BOLTON: Mr. Kleier, do you have any trouble with the dimensional changes?

MR. KLEIER: At the present time we do not. There was one time when the practice was to anneal such things as cylinders, but the practice has not seemed to be successful so at the present time they are not aged at all in any way. They are taken to the machine shop, machined and offered for service. Without aging in any way, they are ready for service. They find that they are sound castings and we gained nothing by heat treating which was thought necessary at one time. If, however, we feel that the castings have internal strains then they are annealed.

J. ROXBURGH: (*Submitted as a written closure*): I would first of all take this opportunity of publicly thanking Mr. Kleier for having so ably presented my paper before the Milwaukee conference, and also the other members present, both for their attendance and the part they took in the discussion, and for the resolution of thanks they passed to me concerning my contribution.

I was delighted to read Mr. Vanick's remarks and to know that he was of the opinion that this type of paper should be indulged in more liberally in order to provoke discussion amongst those foundrymen, who display an enthusiastic interest in both the practical and technical aspects of the branch of the foundry industry, with which they may be associated.

Generally speaking, Mr. Vanick's experience of the various matters he discussed, appears to agree very much with mine, and my suggestion regarding the possible use of Swedish Iron and graphitisers in the manufacture of ingot molds seems to have met with his approval. The experiments, which he carried out in conjunction with some work done by Dr. MacKenzie, are indeed of great interest and the samples of irons of the Swedish type, which he used, showed very desirable properties as regards growth tests, thermal conductivity and low expansivity. He confirms that a high total carbon in ingot mold iron is desirable, as is also a low combined carbon. He evinces also an interest in a high Mn content iron and when he tells me that his company are carrying out some work in the direction of the various points enumerated, I shall certainly look forward to seeing the results, if he would be good enough to publish them in the future.

² Metallurgist, Hunt-Spiller Mfg. Corp., Boston, Mass.

His comments regarding settling pots, which his company buy, made from Bessemer pig only, are extremely interesting and, to myself, particularly the fact that the silicon is about 1.2 per cent in these castings is definitely significant as experiments are being carried out in this country at the present time on ingot molds with silicons down to one per cent, and some work is also being done on these castings with manganese above one per cent. As I remarked in my paper, I think that to improve the service obtained from an ingot mold, a definite structure should be the aim. This seems to be a question of how far one can go with the refinement of the graphite, together with how high one can take the combined carbon content.

Unfortunately, due entirely to a misprint in the preprint, Mr. Vanick, as well as the other members who took part in the discussion, have been misled with regard to the length of time various sized ingot molds should be left in the sand after casting. The preprint of my paper, which I have since had altered, should have read:

20 ton molds out of the sand in 2 to 3 weeks.

40 ton molds out of the sand in 3 to 4 weeks.

60 ton molds out of the sand in 4 to 5 weeks.

I made a particular point of this as I feel that cooling under such normal conditions, tends to anneal the casting, and, therefore, improves the life obtained from the casting in service. In fact, I am led to understand, that some steelworks go to the length of annealing the ingot mold when it is first received into the works before putting it into service.

As the subsequent discussion centered around the length of time a casting should be left in the sand before removal, the above explanation will now, I hope clear the matter up, and it will be quite evident that no argument arises as to the brevity of the period of cooling but that, on the contrary, it is a question of leaving the casting a reasonable time in the sand to ensure that it is allowed to cool down normally.

The comments regarding the heat treatment of large castings are interesting and, I would say, that, like the commentator, it is not my practice to prescribe a definite heat treatment. All I insist upon is that nothing should be done to accelerate the cooling of the casting.

To all those who took part in the discussion, I would tender my warmest thanks and I personally have derived great satisfaction from the fact that the paper has been so well received.

Summary of Second Report
of the
Steel Casting Research Committee
Special Report No. 15, 1936
The British Iron and Steel Institute

By C. W. BRIGGS,* WASHINGTON, D. C.

1. During the year 1936, the British Iron and Steel Institute published a report,¹ prepared by a joint committee of the Iron and Steel Institute and the British Iron and Steel Federation, known as the Second Report of the Steel Castings Research Committee. This 117-page report was considered by the executives of the Steel Division of the American Foundrymen's Association to be a decidedly worthy contribution to the fundamental knowledge on steel castings and they were of an opinion that the members of the American Foundrymen's Association would be much interested in the conclusions presented in this report. Permission to prepare a summary of this report was granted by The Iron and Steel Institute and the following summary discussing the report by authors, was prepared by the writer at the request of the chairman of the Steel Division of the A.F.A.

Section I—INTRODUCTION.

2. The introduction discusses briefly the aims of the committees and lists the committee members.

Section II—PROPERTIES OF STEEL WHICH AFFECT THE QUALITY OF STEEL CASTINGS—DR. R. H. GREAVES.

3. The first part of this paper contains a summary of existing information on the dimensional changes which occur in iron and steel as the metal cools from the liquid condition to atmospheric

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¹Published by The Iron and Steel Institute, 28 Victoria St., London, S. W. 1.

NOTE: This report was presented to the Steel Division Round Table Conference of the 41st Annual Convention, Milwaukee, Wis., May 5, 1937.

temperature, and on the strength and ductility of the steel at temperatures near the melting point.

4. The second part deals with fluidity, with special reference to the practical interpretation of the results of fluidity tests. The spiral test is considered most suitable. In practice, the effective head of metal and the rate of pouring have an influence which may overshadow differences in fluidity measured.

5. Dr. Greaves considers the section on "Physical Properties of Liquid and Solid Steel" in two parts, namely, laboratory measurements and foundry measurements.

Laboratory Measurements

6. A review of laboratory measurements, mostly from the works of Tammann; Benedicks, Ericsson and Ericson; Widawski and Sauerwald; and Desch and Smith on the dimensional changes which occur in iron and steel as the metal cools from the liquid condition to atmospheric temperature, leads to the following somewhat tentative conclusions:

(1) Liquid contraction occurs in pure iron above its melting point to the extent of about 0.8 per cent of the volume at atmospheric temperature per 100° C. (180° F.). This value is slightly diminished by an increase of chromium and aluminum, and increased by carbon, silicon, manganese and phosphorus.

(2) The contraction of pure iron in solidification is about 3 per cent of its volume at atmospheric temperature. This is increased to a maximum of 4 or 5 per cent with 1 per cent carbon, and then diminishes again with a further increase in carbon.

(3) The linear solid contraction of pure iron, from the freezing point downwards, is 2.45 per cent of its length at atmospheric temperatures. This decreased slightly to about 2.3 per cent with increase of carbon to 0.8 per cent.

(4) The equivalent values of the contraction of iron referred to the volume at atmospheric temperature and to the volume of solid at the melting point are:

Percentage of volume of solid at.....	20° C. (68° F.)	1530° C. (2786° F.)
Liquid contraction per 100° C., per cent.....	0.8	0.75
Freezing contraction, per cent.....	3.0	2.85
Solid contraction, per cent.....	3x2.45=7.35%	3x2.32=6.96%

(5) Indications are that the total volume contraction from 1600 to 20° C. (2912 to 68° F.) (expressed as a percentage of the volume at atmospheric temperature) is increased from 10.5 to 14.0 per cent as the carbon rises from 0.06 to 1 per cent, but that it is unchanged as a result of the addition of small quantities of alloy elements, except aluminum by which the contraction on solidification is possibly reduced.

Foundry Measurements

7. Much work has been carried out on the practical determination of contraction which is more nearly related to the behavior of cast steel in the mold. These measurements are summarized as follows:

(1) Solid contraction studies on freely contracting steel show that there is fairly good agreement between the laboratory and foundry measurements.

Authorities	Carbon Per Cent	Solid contraction (as percentage of solid at freezing point)—per cent
Laboratory measurements	Nil to 0.8	Decreases from 2.32 to 2.15
Wust and Schitzkowski.....	0.1 to 0.9	Decreases from 2.39 to 2.22
Körber and Schitzkowski.....	0.15 to 0.5	Average 2.20
Briggs and Gezelius.....	0.08 to 0.9	Decreases from 2.47 to 2.18

(2) Freezing contraction was obtained by Briggs and Gezelius by conversion and calculations to be 2.7 per cent of the specific volume of liquid steel or 3.0 per cent of the specific volume of the solid steel at atmospheric temperature.

(3) Liquid contraction. No foundry measurement in cast steel.

(4) Hindered contraction cannot be entirely avoided in practical casting and may be, under some instances, extremely high. Körber and Schitzkowski showed that a temperature of 1300° C. (2370° F.) was critical in the formation of hot tears due to hindered contraction. Briggs and Gezelius showed the magnitude of the stresses that may arise on various types of hindered contraction and the amount of solid contraction arising from these conditions.

(5) There is considerable variation in reported studies on the strength and ductility properties of steel which has been reheated from atmospheric to very high temperatures; however, the work of Piwowarsky, Bozie and Söhnchen appears to be the most outstanding. They conclude that above 1000° C. (1830° F.) differences in tensile strength, depending on the mode of steel making, disappear and that all steels at

this temperature had a tensile strength of about 5,000 lb. per sq. in., which fell towards zero with rise of temperature to 1350-1450° C. (2460-2640° F.). The reduction of area increased with temperature to a maximum of 80 to 99 per cent at 1250° C. (2280° F.) after which it rapidly fell off to zero at temperatures of about 1350° C. (2460° F.). Because of variations that existed in the values obtained in the study of reduction of area of the different makes of steel, the authors presumed that basic open-hearth steels have the highest capacity for deformation at temperatures not far removed from their freezing points and preference should be given to them when looking for a steel which will tear. Dr. Greaves, however, points out that a study of the strength and ductility of cast steel as it cools in the mold may bring out an entirely different set of conditions from that obtained on reheated steel. This point will definitely be shown to be true on reviewing Mr. Hall's paper in Section IV.

8. The second part of Dr. Greaves' paper discusses in detail the fluidity of steel in relation to the method of manufacture, composition and temperature of casting. By "fluidity" is meant the property of flowing freely and hence the ability of the molten metal to fill a mold.

9. Dr. Greaves traces the development of the fluidity test and shows that the spiral mold is the most adaptable design for quantitative study. The following conditions were found to have a definite effect on the spiral fluidity test:

(1) Effect of spiral cross section. The distance the steel runs increases with increase of the ratio of cross-sectional area to the perimeter. Long runs may not mean increased sensitivity of the test.

(2) Effect of temperature. The spiral length usually increases as temperature increases. This does not necessarily imply that the steel is more fluid at the higher temperatures, since it may be due to the increased range of temperature through which the steel cools while it is flowing in the spiral.

(3) Effect of conditions of casting. Foundry conditions such as pouring from ladles and hand shanks may not give correct fluidity measurement due to inability of controlling rate of pouring and constant static heads.

10. The possible causes of lack of fluidity in steel were listed as:

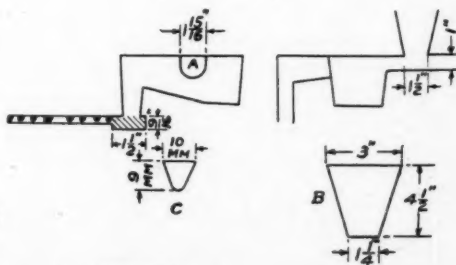
- (1) Viscosity.
- (2) Surface tension.
- (3) Surface oxide films.
- (4) Suspended inclusions.

Section III—THE FLUIDITY OF IRON-CARBON AND OTHER IRON ALLOYS—J. H. ANDREW, R. T. PERCIVAL and G. T. BOTTOMLEY.

11. The authors made a few preliminary experiments using the spiral mold fed by a horn gate that has become somewhat standard in this country and known as the Saeger-Bureau of Standards fluidity mold. Since the length of run was not sufficient, the horn gate was replaced with a straight down gate feeding into a small reservoir. A design of the mold used is shown in Fig. 1.

12. The alloys were melted in an oil-fired, crucible furnace. The crucible held a maximum of 25 lb. of melted metal which served for two castings for each composition. The two tests were obtained at temperatures varying by about 50° C. (90° F.). Two thermocouples of tungsten-molybdenum were used in sheaths made of alundum cement to measure the temperature.

13. The mold was made with a core sand facing and the backing sand was Yorkshire sand diluted with floor sand. The mold was baked at 480° F.



A - OVERFLOW
B - CONICAL FEEDER HEAD
C - SPIRAL SECTION

FIG. 1—FLUIDITY TEST CASTING DESIGN.

14. The authors collected data on the following systems: Iron-carbon, iron-phosphorus, iron-silicon containing 0.4 per cent of carbon and iron-manganese containing 0.5 per cent of carbon.

Iron-Carbon

15. Twelve alloys ranging from 0.02 to 3.75 per cent carbon were made and the results plotted. Two sets of temperature-fluidity curves for each alloy were constructed. In one set, the liquidus was selected as the point where the alloy possesses zero fluidity, and in the other the solidus was used. Fig. 2 shows an example of these curves. These curves were then used for constructing a curve showing the relationship between fluidity and composition at 1600° C. (2910° F.) as may be seen in Fig. 3. As one would expect, the addition of carbon to iron increases the

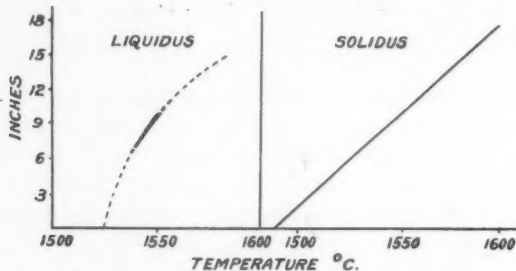


FIG. 2—FLUIDITY-TEMPERATURE CURVES OF A 0.17 PER CENT CARBON ALLOY, TAKING THE LIQUIDUS AND SOLIDUS RESPECTIVELY AS ZERO FLUIDITY.

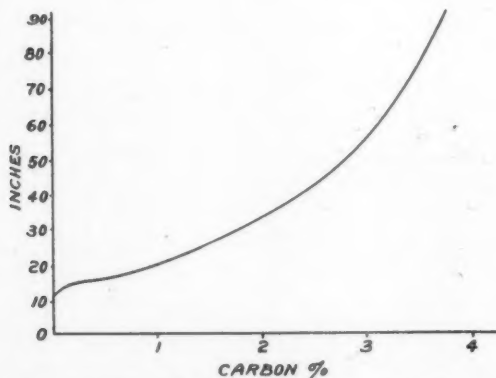


FIG. 3—FLUIDITY CURVE OF IRON-CARBON ALLOYS AT 1600° C. (2910° F.)

fluidity, provided the casting temperature is kept constant. This increase, however, is very slight over the peritectic range, that is, between 0.07 and 0.71 per cent of carbon. With further increases of carbon beyond 0.71 per cent, there is a noticeable continuous increase in fluidity up to the eutectic composition (4.3 per cent carbon).

16. Fluidity values for each alloy were obtained from the fluidity-temperature curves at temperatures 10° C., 30° C., and 50° C. (18° F., 54° F., and 90° F.), respectively, above the point taken as zero fluidity. From these figures, the fluidity-composition curves shown in Fig. 4 were plotted. From these curves, it will be observed that the general form of the liquidus and solidus curves are similar. The liquidus curves show a decrease in fluidity from pure iron to 0.07 per cent carbon, then an increase of 0.17 per cent, the constant fluidity between 0.17 per cent and 0.71 per cent carbon, followed by a decrease to a minimum at 1.8 per cent of carbon, after which there is a steady increase up to 4.3 per cent of carbon. In the solidus curves, there is a marked decrease in fluidity from 0.17 per cent of carbon to 0.71 per cent of carbon.

17. Correlating these results with the equilibrium diagram, it would appear that where the liquidus-solidus range is a maximum, the fluidity is a minimum, and, therefore, it seems possible to forecast the comparative fluidity of an alloy of iron and carbon from its equilibrium diagram.

18. In the iron-phosphorous alloy series, the fluidity decreases with increase of phosphorous content to a minimum of 2.6 per cent of phosphorus, at which point the eutectic range commences. The fluidity curve shows a maximum value at the eutectic composition.

19. The iron-manganese alloys show an increase in fluidity up to about 3 per cent manganese. From 3 per cent to 14 per cent, the fluidity is nearly constant and above 14 per cent it rises rapidly.

20. The iron-silicon series shows a steady increase of fluidity with an increase of silicon content.

Section IV—THE STRENGTH AND DUCTILITY OF CAST STEEL DURING COOLING FROM THE LIQUID STATE IN SAND MOULDS—
H. F. Hall.

21. To meet the need for more knowledge of the properties and behavior of cast steel, Mr. Hall has devised an ingenious apparatus for making tensile tests on castings. To obtain results of

value, it is essential that the tests should be unaffected by any reheating treatment, and they should therefore be made under natural conditions of cooling in the mold. Accordingly, special apparatus was devised for making rapid determinations of the strength and ductility of castings under the required conditions. The temperature gradient in the cross-section of the test-piece.

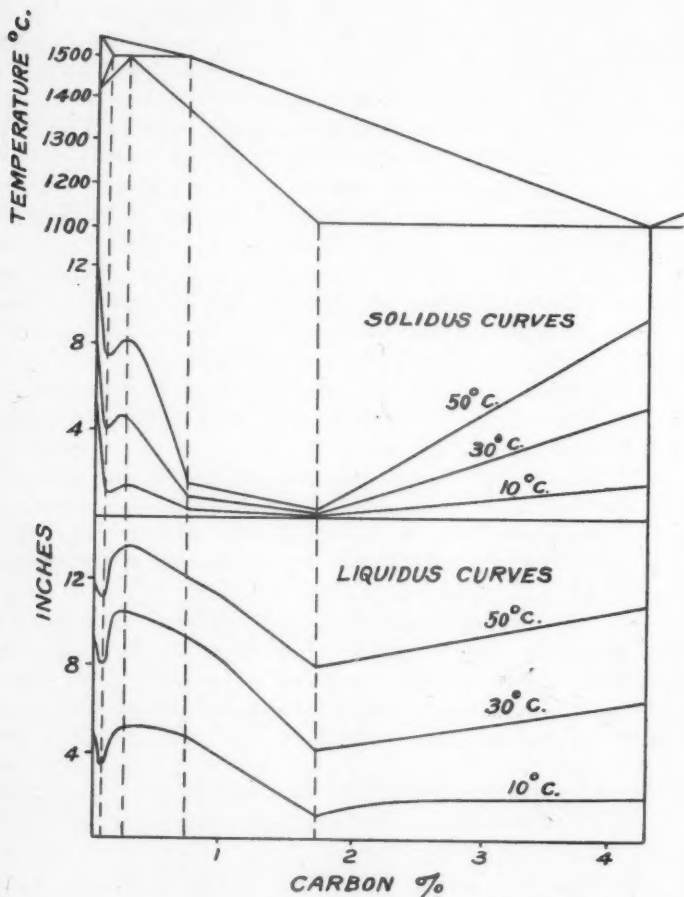


FIG. 4—CONSTITUTIONAL DIAGRAM OF IRON-CARBON ALLOYS AND FLUIDITY CURVES AT 10°, 30° AND 50° C. (18°, 54° AND 90° F.) ABOVE THE LIQUIDUS AND SOLIDUS.

although undesirable in normal testing procedure, is characteristic of all parts of a casting when cooling, and any effect it may have on strength properties is taken into account in the results of the tests.

22. Briefly described, the procedure consists of casting a group of test-bars simultaneously in one mold and subjecting each in succession to a tensile test. The times chosen for the tests control the temperature at which each is performed. With prior knowledge of the rate of cooling the tests can be made at a predetermined series of temperatures, with the first as near as may be desired to the point of solidification.

23. Preliminary experiments were made to determine details for the design of the special mold and testing apparatus required. The best results were obtained by making the test pieces parallel throughout their length and obtaining the necessary grip by casting on to screw-threaded bolts of smaller diameter than the test piece. The upper bolt was held in position by a separate tapered core filling in the mold and loaded externally to prevent rising under the pressure of metal when poured. This form of test-piece proved satisfactory for casting, gripping, and the location of the fracture.

24. Details of the mold ultimately adopted are shown in Fig. 5. It required from 25 to 30 lb. of steel, and there were provisions for eight test pieces one inch in diameter. One test piece was left undisturbed throughout the test for recording the temperature; two thermocouples set in a sand plug, the inner face of which was molded to the test piece contour, were inserted in the side of the mold and provided for simultaneous records of axial and skin temperatures.

25. All other test-pieces were cast in separate cores. These were tapered on the outside to make an easy fit in the mold, and fitted with an eyebolt at the upper end. When the test was performed the sand core broke at the same position as the test-piece and the upper portion was freely drawn from the mold with the test-piece enclosed. The sand core was weakened by burning of the oil bond by the steel, and did not appreciably affect the load; if the steel be slightly ductile the core must break before the maximum load is attained, when it can have no effect on the value recorded.

26. The test-pieces were molded with their axes inclined to the vertical to coincide with the axis of pull during test. Accurate

alignment and spacing of the patterns during ramming was obtained with the aid of a dowelled ring.

27. The sand used for making the molds consisted of equal parts of Cumberland red sand, Leighton Buzzard medium, and Erith fine silica sand with 6 per cent by volume of oil binder.

CONCLUSIONS

Influence of Composition on Tensile Strength

28. The rate of increase of strength was generally lowest during the early period of test, with strength below 800 lb. per sq. in., and before the temperature had attained its maximum rate of fall. The 0.1 per cent carbon steel, which developed early ductility, increased in strength at a uniformly high rate. In fact, at a given

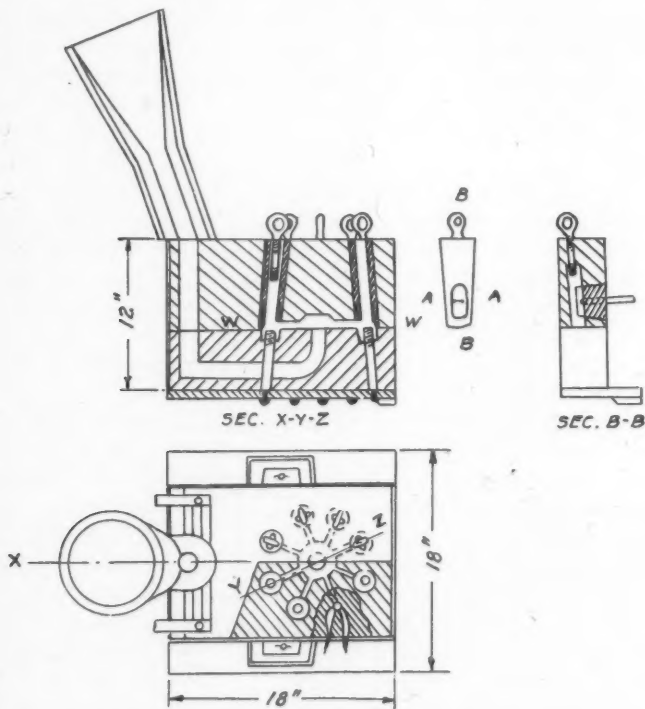


FIG. 5—MOLD FOR 8 TEST PIECES CAST IN CORES.

high temperature the strength of a carbon steel diminished with increase of carbon above 0.1 per cent; but if allowance was made for the lowering of the solidus temperature, the gain in strength on cooling through a definite temperature interval below the solidus was rather more in high—than in low—carbon steels. The variations in strength obtained with small alloy additions were within the limits of those produced by variation of the carbon content in plain carbon steels.

29. Comparative values determined with rates of strain of 0.046, 0.21 and 1.0 in. per sec. are available only for the 0.3 per cent carbon steel. With the slow rate of strain, 800 lb. per sq. in. was attained at the same temperature as with the medium rate, but 1400 and 2000 lb. per sq. in. were recorded at temperatures about 50° C. (90° F.) and 100° C. (180° F.) respectively lower than with the medium rate of strain. At the high rate of strain the temperature for each stress was about 25° C. (45° F.), higher than that for the medium rate of strain.

Influence of Composition on Ductility

30. At temperatures above 1300° C. (2370° F.), ductility was found only in steels containing less than 0.2 per cent carbon, and with the exception of these and some alloy steels mentioned later, the lowest ultimate stress accompanying ductility was 1600 lb. per sq. in.

31. The appearance of ductility, except in the low-carbon steels, occurred after the rate of increase of strength and fall of temperature had attained their maximum values. The limits of stress and temperature, between which this occurred, vary but little in a wide range of compositions. No stress greater than 2000 lb. per sq. in. and no temperature lower than 1250° C. (2280° F.) was recorded without some elongation. The main distinguishing feature between different steels was the rate at which elongation increased with further fall in temperature.

32. As it is difficult to judge with accuracy the temperature of the first appearance of ductility, the strength and temperature accompanying 5 per cent elongation at fracture have been taken as an indication of the relative conditions under which ductility appeared in the steels tested; the steels are compared on this basis in Table 1. With carbon not higher than 0.1 per cent the temperature was above 1400° C. (2550° F.). The 0.14 per cent carbon steel (PRD) possessed a strength of 1120 lb. per sq. in. with 5

per cent elongation; in the absence of a temperature record, the temperature is estimated at about 1360° C. (2480° F.). In the medium-carbon steels (0.2 to 0.4 per cent of carbon), the temperature fell to the range of 1295 to 1270° C. (2365 to 2370° F.) before 5 per cent elongation occurred at fracture. For similar elongation in the 0.87 per cent carbon steel (PAO), the temperature had fallen to 1220° C. (2230° F.) with a stress of about 2000 lb. per sq. in.

33. These values for steels of different carbon contents are plotted in Fig. 6, in relation to the liquidus and solidus temperatures of the iron-carbon alloys. The corresponding values of the temperatures at the axis of the test-bars are also included. It will be seen that, whether these or the skin temperatures are consid-

Table 1
STRENGTH AND TEMPERATURE ACCOMPANYING 5 PER CENT
ELONGATION AT FRACTURE

(Rate of Strain, 0.21 inch per second)

Casting	Composition Per cent	Ultimate Stress	Skin Temp.	
		Lb. per sq. in.	°C.	°F.
PRF	0.04C	240	1405*	2561
PAK	0.10C	460	1405	2561
PRD	0.14C	1120	1360	2480
PRE	0.20C	1700	1280	2336
PAM	0.25C	1840	1295	2363
OWO	0.26C	1720	1290	2354
OWM	0.37C	2320	1285	2345
OEL	0.39C	1760	1270	2318
PAN	0.42C	2220	1270	2318
PAO	0.87C	1940	1220	2228
OWV	0.14C, 1.25 Cr	1840	1315	2399
OWK	0.19C, 2.0 Mn	1680	1310	2390
OWZ	0.33C, 0.25 V	2140	1275	2327
OWQ	0.39C, 1.0 Ni	—	1275	2327
OWS	0.21C, 3.1 Ni	1260	1270	2318
OWT	0.20C, 5.0 Ni	2040	1270	2318
PAQ	0.27C, 0.3 Mo	2300	1265	2309
PER	0.30C, 2 Ni, 18 Cr	2060	1255	2291
OWR	0.42C, 3.45 Ni	2020	1245	2273
PEQ	0.33C, 2 Mn, 0.3 Mo	2200	1230	2246
PAL	0.15C, 8 Ni, 18 Cr	2520	1230	2246

* This steel gave 17 per cent elongation with skin temperature 1406° C. (2560° F.), core temperature 1460° C. (2660° F.).

ered, there is a considerable range below the solidus temperature before appreciable ductility (viz., 5 per cent elongation) is attained, and that this range is greatest for a 0.2 per cent carbon steel.

34. Nickel up to 5 per cent or small additions of chromium, vanadium, or molybdenum in 0.2 to 0.4 per cent carbon steels had no appreciable effect on the temperature, which fell to about 1270° C. (2320° F.), as for the carbon steels, before 5 per cent elongation was reached. The strength was 1300 lb. per sq. in. for the lower nickel steels and 2000 lb. per sq. in. for the others.

35. The nickel-chromium steels OWU and OWW, for which no temperatures were recorded, resembled the nickel steels OWQ and OWS, in developing 5 per cent elongation with the low stress of 1300 lb. per sq. in. The 3.45 per cent nickel steel (OWR) with

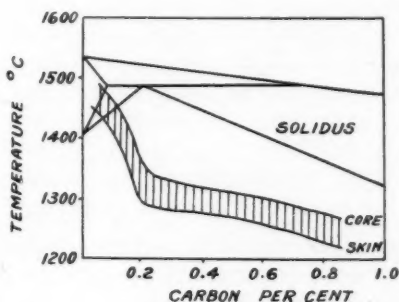


FIG. 6 TEMPERATURE OF TEST-PIECES GIVING 5% ELONGATION

FIG. 6—TEMPERATURE OF TEST PIECES GIVING 5 PER CENT ELONGATION.

0.42 per cent of carbon fell to the exceptionally low temperature of 1245° C. (2275° F.) with a stress over 2000 lb. per sq. in. before registering 5 per cent elongation.

36. Most of the high-alloy steels tested failed to acquire an elongation of 5 per cent at fracture in the final test. With the castings of 12 per cent manganese and 14 and 30 per cent chromium steels, the tests ended prematurely with low stresses, but with the tungsten steels, the elongation was not produced with the maximum stress available. The 18 per cent chromium steels with 2 and 8 per cent of nickel reached temperatures of 1255° and

1230° C. (2290 and 2245° F.), respectively, with a stress above 2000 lb. per sq. in. when 5 per cent elongation was recorded.

37. The tests on the 1 per cent copper and 0.07 per cent phosphorus steels also ended prematurely, but the temperature had fallen to 1240° C. (2265° F.) with an elongation of less than 5 per cent and a stress of about 2000 lb. per sq. in.

38. An increased rate of strain applied to a 0.3 per cent carbon steel was found to raise the temperature at which elongation became apparent. Each five-fold increase in the rate (approximately 0.04 to 0.2 and 0.2 to 1 inch per min.) raised this temperature about 20° C. (36° F.).

Section V—THE WORK AND PROGRAMME OF THE MOLDING MATERIALS SUB-COMMITTEE—W. J. REES.

39. This section deals with the program for future study of molding materials and makes provision for investigations on: Testing of steel molding sands, effect of mold washes, behavior of synthetic bonds, reclaiming of sand, properties of core sands, volume changes in molding sands with temperature, and effect of thermal conductivity of the mold on the casting.

Section VI—THE PRESENT POSITION OF RADIOLOGICAL EXAMINATION OF STEEL CASTINGS—V. E. PULLIN.

40. The author gives illustrations of typical flaws in castings, as shown by radiography, together with photographs of the actual appearance of the defect after dissection.

Problems in Bronze

By HAROLD J. ROAST,* Montreal, Que.

1. When searching for a title for this paper, the writer chose "Problems in Bronze" as this left him an open door for much of the scattered information that is in his possession as a result of some thirty years of delving into metal problems.

2. The study of any problem presupposes the process of thinking and if problems are to be satisfactorily solved this thinking must be logical and be associated with a determination to overcome all the difficulties that present themselves and to never cease trying until the solution is reached. It is the writer's opinion that a problem is not really conquered until one can produce both the bad condition that is being studied and the good condition at will. To correct a problem in metal by some process but to be unable to take that satisfactory product and make it unsatisfactory is really only to have solved half the problem.

3. Berton Braley sums up this matter very effectively when he says:

*"Back of the beating hammer by which the bronze is wrought,
Back of the workshop's clamour the seeker may find the
Thought,*

*The Thought that is ever master of Bronze and Steam and
Steel,*

That rises above disaster and tramples it under heel."

4. It is proposed to discuss the subject in a manner that will endeavor to interest the foundryman, the metallurgist, the engineer, foundry executive, salesman and, finally, the most important factor, namely the purchaser, more or less in the order given. Problems in bronze are as varied as the leaves of a tree, which, if

* Vice President, Canadian Bronze Co., Ltd.

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the writer is correctly informed, never exactly duplicate each other.

5. We can better, perhaps, study the subject for a short time by starting with solid metal, rapidly discussing melting problems and so to casting problems. It is not the intention to carry the subject past the casting stage and there will not be included fabricated metal such as extruded, wire, hammered metal, etc. Doubtless much of that which is written will sound very elementary and commonplace to many but the excuse is that it is simple things that are so often neglected and that no matter how much experience some of us may have had there is always the danger in searching for the key to the difficulty in some obscure scientific explanation thus beclouding our viewpoint and missing the obvious.

GOOD METAL

6. A good start is a great help and good metal is a *sine qua non* for successful castings. There will be problems enough develop as this metal is melted, cast into sand, etc. By good metal one does not necessarily mean virgin metal. It has been definitely proved that good scrap will give just as satisfactory results as virgin metal.

7. Gassing by both oxidizing gases and reducing gases is the first thing to be avoided. It seems such a pity, for example, to buy ingot copper and put more in the crucible than can be covered by lid or flux, thus having it sit on top of the fire and become changed from high quality and high priced copper to metal of a quality worse than the cheapest scrap on the market, yet this is often done.

8. In general glass is the safest protector from gas absorption when melting bronze. Many alloys are distinctly absorptive of carbon monoxide and react with carbon at a high temperature, examples of which are Monel metal, nickel and silicon bronzes. The placing of charcoal in a ladle and the pouring of molten metal upon it frequently results in gases naturally present in the charcoal pouring out into the molten metal and being in part retained by it. For a neutral covering glass is to be preferred to charcoal.

SHRINKAGE

9. We now turn to the question of shrinkage. Let us take a specific instance, namely that of P. M. G. silicon bronze, giving us an example of the importance of the avoidance of shrinkage

areas both external and internal. The casting in question was of the shape as shown in Fig. 1. The weight of the casting was approximately 400 pounds without risers and about 800 pounds with risers.

10. The problem in this bronze was to feed the heavy cross-section, amounting to some $3\frac{1}{2}$ in., as well as the thinner one in. cross-sections at each end. Lack of proper feeding had resulted in internal intercrystalline shrinkage areas at the junction between the differences of cross-section which in time and under use started an internal crack which became progressive and finally reached the outside, causing failure. Also large shrinkage cavities were

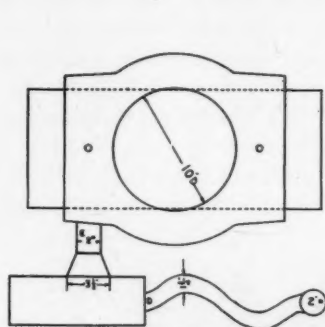


Fig. 1.—Plan

Weight of riser	400 lbs.
Weight of casting	400 lbs.
Temp. of metal	1900° F.

Iron box and dry sand mould.

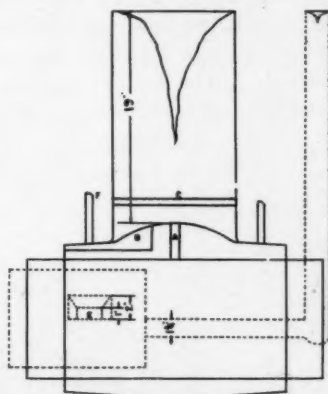


Fig. 2.—Elevation

FIG. 1—SKETCH OF METHOD OF MAKING SILICON BRONZE CASTING SHOWING GATES AND RISERS.

found to be present in the heavy cross-section, which in their turn, especially when they were broken into by a hole drilled in for any purpose, themselves acted as starting points for progressive fractures.

11. As it is believed that it is more instructive in discussing the methods used to obtain a satisfactory casting to include those which were not satisfactory some of these latter will be discussed.

12. One method was to make the casting in green sand, casting it both vertically and horizontally. Owing to the large amount of metal passing over the sand, the green sand mold introduced sand occlusion problems. It was decided, therefore, to make the casting in an iron box with a completely oven dried sand mold.

The core, of course, was of dry sand in both cases. The dry sand mold, cast vertically, was fed by risers on the thin cross-section, with the result that the thin cross-section solidified before the heavy section was solid, causing an internal crack at the junction of the cross-sections and some very considerable cavities in the heavy part of the casting. This was accentuated by pouring the casting from the bottom, which it was desired to do in order to avoid the trapping of oxide films by dropping the metal in from the top.

13. The casting was then made on its side and it was decided, not to make two bites at a cherry, but to put on a riser that practically covered the whole upper area of the heavy cross-section and to make it sufficiently high to guarantee that the shrinkage produced by the casting and riser combined would not reach the casting itself. In the first casting made this way the metal was allowed to come up in the riser, the riser being left open. The whole system cooled in the usual way but owing to the fact that the riser naturally chilled where exposed to the air, the metal set on the top thereof and as the shrinkage continued from

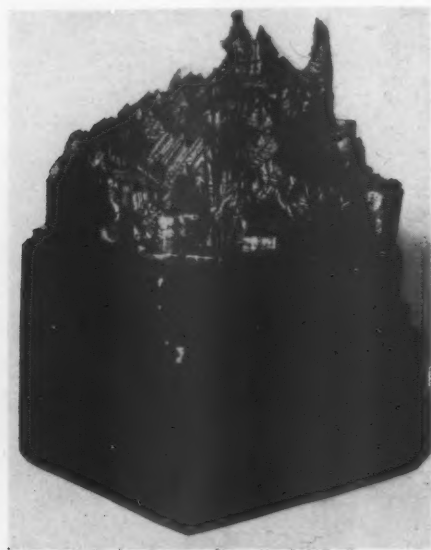


FIG. 2—METALLIC CRYSTALS.

beneath, the metal was pulled away from the underneath of the top of the riser, with the result that an especially beautiful form of crystals occurred (Fig. 2).

14. However, what was wanted was that all the metal should be free to follow the pull of the cooling metal beneath and, therefore, when the next casting was made graded charcoal to a depth of about 3 in. was thrown on the metal as it came up the riser. By graded charcoal is meant charcoal that goes through a $\frac{1}{8}$ -in. mesh sieve but is retained on a $\frac{1}{16}$ -in. mesh sieve, the result being a granular charcoal free from dust. This time when the system cooled the burning charcoal kept the surface of the metal from freezing until the shrinkage beneath had ceased, with the result that a perfect feed occurred. Proof of this was found when the casting was broken and a cross-section was taken out (Fig. 3) corresponding to the one which had shown trouble when the casting was made vertically.

15. Further, a cross-section was removed at the thickest part of the casting under the riser. This showed a perfectly uniform density throughout the cross-section which is characteristic of silicon bronzes and manganese and aluminum bronzes.

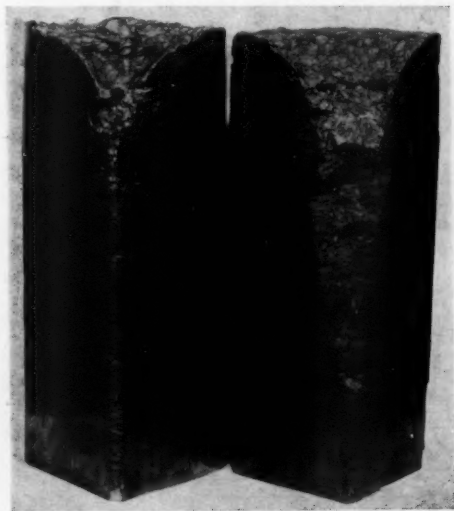


FIG. 3—COMPARABLE RISERS SHOWING SHRINKAGE DUE TO RISER AND SHRINKAGE DUE TO CASTING.

BURNING IN

16. It was desired to ascertain the burning in qualities of silicon bronze and to this end a small hole on the thin cross-section of the casting was chiselled out and hot silicon bronze burned in in the usual manner. We were fortunate in getting a fracture through this burned in section. It was seen on examining the specimen that the two metals had joined completely, the difference in appearance being due to the fact that the burned in metal is really, of course, a chill casting as compared with the surrounding metal which is comparatively slowly cooled. The tear necessary to separate the metal throughout the cross-section indicated the stability of the burned in area.

CONTROL TEST BARS

17. It was, of course, desirable to be sure that the metal used in this casting was in a normal condition. Control test bar blocks, as shown in Fig. 4, were therefore cast from the same pot and at the necessary varying temperatures which experience had shown would indicate any gassed or oxidized condition of the metal. The keel bar was sawn half way through and fractured. This fracture showed the metal to be in a normal condition.

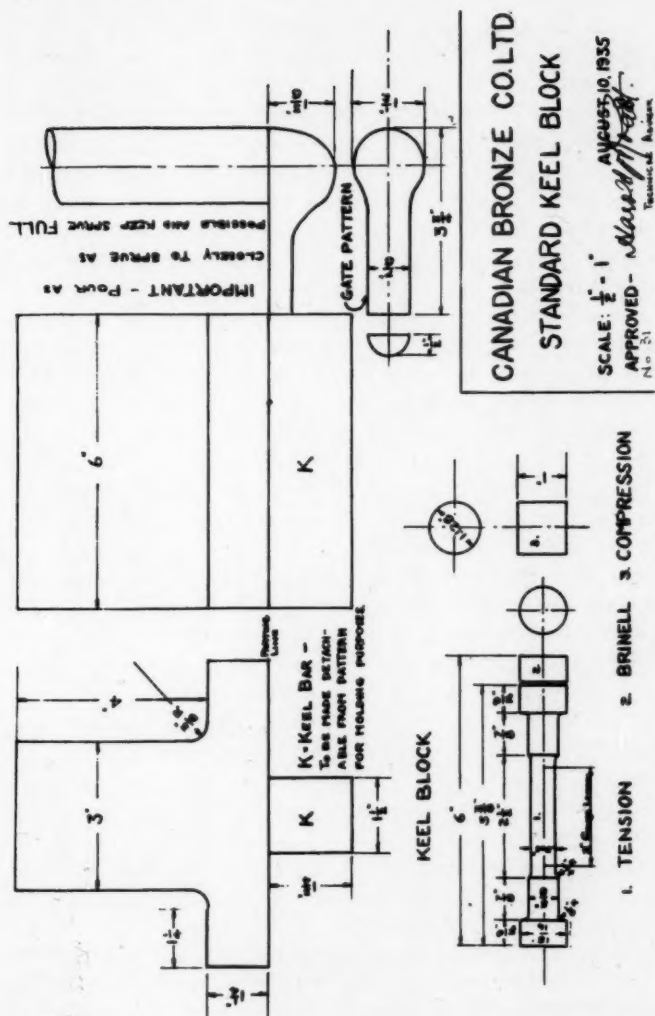
SEGREGATION

18. The cooling of 400 pounds of metal in cylindrical form gave us a special opportunity to look out for chemical segregation and one small area was found at the apex of the shrunken cone in the riser which was white in color and brittle in nature as compared with the yellow color and extreme toughness of the rest of the metal. Analysis of this showed it to contain:

	Segregation Section %	Normal Section %
Copper	90.97	94.40
Silicon	6.44	4.00
Iron	2.23	1.50
Manganese	0.10	0.05
Phosphorus	0.26	0.05

19. The result of these investigations put the foundry in a position of being able to assure its customer that it could make good or bad castings off their pattern at will and the problem was considered as solved.

20. One might, perhaps, parenthetically remark, that not



every company gives the necessary freedom to enable the metallurgist to incur the expense involved in making and breaking a series of castings involving 800 pounds of metal each time. It has been definitely shown, however, that providing the metallurgist uses judgment as to what problems are worthy of such investigation and what are to be classified as purely "interesting" research, thorough attack of genuine commercial problems is a sound business investment.

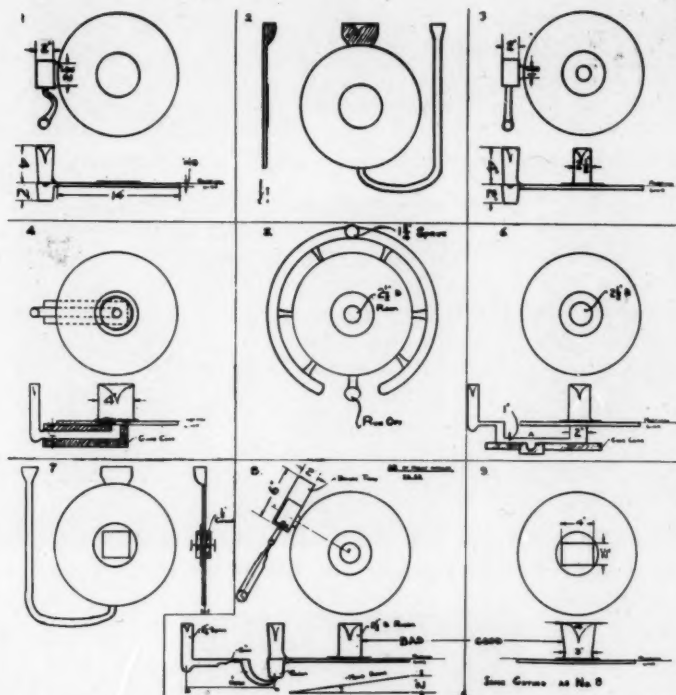
21. Some time has been spent on this one casting because it was thought well to give a detailed example of one method of solving a foundry problem. Fig. 5 shows various attempts that were made to produce a disc in a medium shrinkage, rather dross forming alloy that had to be perfectly free from dross on all surfaces and which upon being fractured into several pieces, including fracture through the center, had to have a uniform grain size. It is believed that such a uniformity of grain size, and not only uniformity but smallness of grain size, is essential to getting the best anti-corrosion qualities out of any given metal.

22. After developing the method shown in No. 9 of Fig. 5 and using this method, 19 castings were made without dross, were shipped and found satisfactory. Temperature of pouring common to all was at 2000° F. Green sand (Albany No. 1 and 0 mixed) was used with the molds blackened with highest grade plumbago. The molds were tipped. By a satisfactory casting in this instance was meant a plate free from dross or dirt either on the surface or elsewhere and having a uniform grain size as shown by fracture throughout all alterations of the cross-section.

23. Figs. 6, 7 and 8 show various views of a nickel silver casting and the way in which it was made satisfactorily. The temperature of pouring was 2400° F., the sand used was synthetic sand (silica sand plus clay), the mold was dried and the metal was poured into a basin which communicated with the central gate-riser through eleven pop gates $\frac{3}{8}$ in. dia. each. Fractures at the base of the gate-riser and the gas vents on the outside all showed thoroughly uniform grain. Machining of the boss and of the casting as a whole showed freedom from any form of dirt.

24. Before leaving the foundry point of view, we would like to draw attention to Fig. 9, which shows a form of gate for high shrinkage alloys that has been in constant use for many years in a variety of plants. The author became acquainted with this form of gating through the courtesy of N. K. B. Patch, of the

Lumen Bearing Company, of Buffalo. This may look like a rather time consuming molding proposition but the results obtained in the certainty of good castings free from dirt and shrinkage at the gate more than offsets the expense.



- FIG. 5.—PROGRESSIVE TRIALS TO GET A SATISFACTORY SILICON BRONZE DISC.
- (1) COMMON DIRECT GATING. NO PROVISION FOR RISER ON CASTING. DIRT ON COPE SIDE AND SHRINKAGE IN CROSS-SECTION CENTRAL FRACTURE.
 - (2) CAST VERTICALLY TO GET AWAY FROM DROSS. DIRT STILL THERE, AS ALSO SHRINKAGE.
 - (3) SAME AS NO. 1, BUT SMALLER GATE AND A RISER (RISER WRONG SHAPE). DIRT STILL PRESENT. FRACTURE TO ONE SIDE OF RISER O.K.
 - (4) UNDERNEATH APPROACH. METAL WAS SEEN TO SQUIRT IN, THEREFORE DROSS. FRACTURE AT SIDE OF RISER O.K.
 - (5) GATED AS FOR ARCHITECTURAL WORK WITH RISER IN CENTER. LESS DIRT BUT NOT GOOD. FRACTURE AT SIDE O.K.
 - (6) LARGER ENTRY THAN NO. 4 TO AVOID SQUIRTING AND SUPPOSED DROSS TRAP AT A. (THIS SHOULD HAVE BEEN UPSIDE DOWN IF IT WAS TO CATCH DROSS.) SAME RESULT AS NO. 4.
 - (7) SAME AS NO. 2 BUT WITH CHILLS TO OFFSET SHRINKAGE. SHRINKAGE OVERCOME BUT DROSS STILL BAD.
 - (8) PRINCIPLE IS THAT OF ELIMINATING DROSS BEFORE METAL ENTERS CASTING. SHRINKAGE IN CENTRAL CROSS-SECTION FRACTURE, CRACK AT BASE OF RISER, ALL DUE TO WRONG SHAPE OF RISER. MOLD TIPPED AS INDICATED.
 - (9) SAME AS NO. 8, BUT CORRECT SHAPE OF RISER.

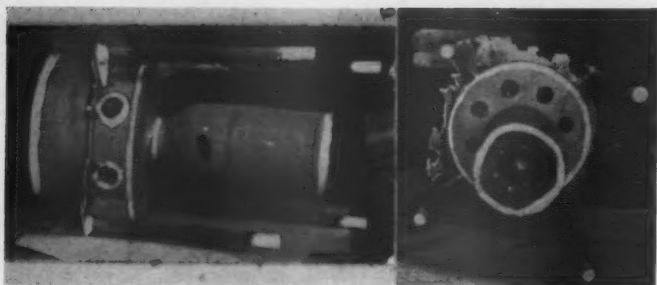


FIG. 6—SATISFACTORY METHOD OF GATING AND RISERING A NICKEL SILVER CASTING.



FIG. 7—THE ROUGH CASTING (LEFT) AND SIDE VIEW OF CASTING SHOWN IN FIG. 6.



FIG. 8—TOP OF THE CASTING OF FIG. 6.

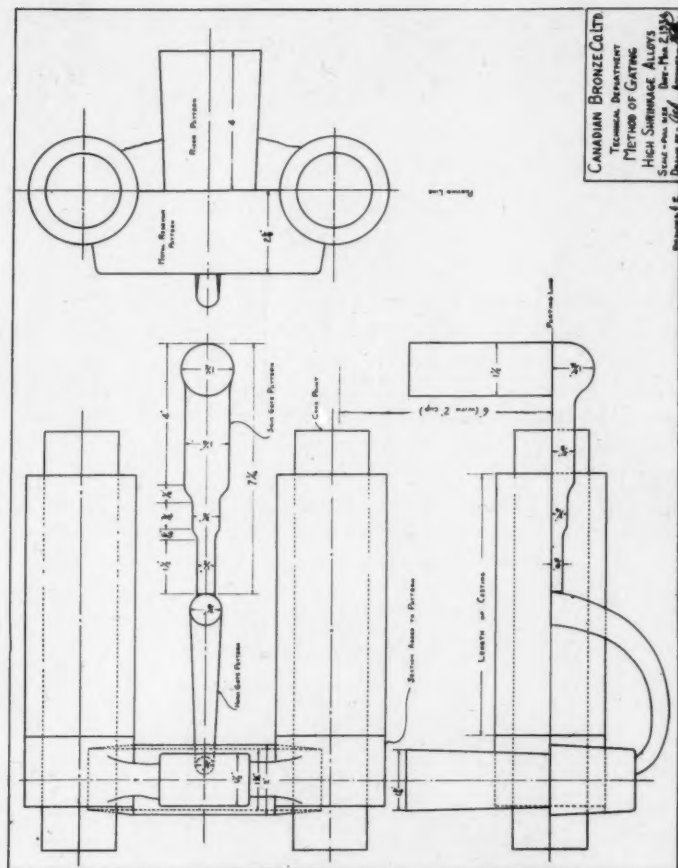


FIG. 9—METHOD OF GATING HIGH SHRINKAGE ALLOYS.

25. Perhaps it might not altogether be a waste of time to draw attention to a very common error of molders in their methods of connecting the sprue to the casting. Fig. 10 (upper) shows that the sprue can draw from the casting instead of feeding it. (This form of connecting the sprue to the casting appears in Fig. 4, but in this case the mass of metal precludes any possibility of the sprue pulling on the casting.) The correct form of joining the sprue to the casting is shown by the center sketch of Fig. 10.

26. Blind risers are not used as much as they might be to provide for shrinkage. The lower sketch of Fig. 10 indicates such

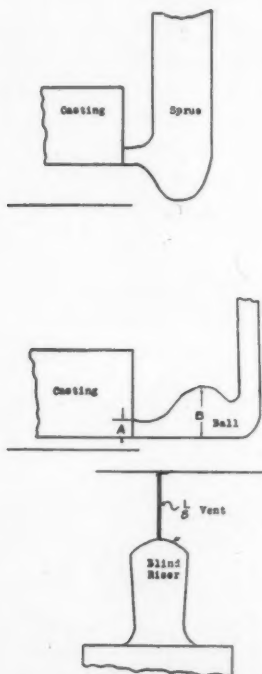


FIG. 10—RIGHT AND WRONG METHODS OF GATING.
(UPPER FIGURE) DO NOT GATE THIS WAY WHEN IT IS DESIRED TO AVOID SHRINKAGE. THIS DRAWS ON OR FROM THE CASTING INSTEAD OF FEEDING IT.
(CENTER FIGURE) BALL GATE. THIS TYPE OF GATE WILL AVOID SHRINKAGE AT THE GATE AREA. RELATION OF HEIGHT A:B IS 1:3 OR 4.
(LOWER FIGURE) BLIND RISER TO PROVIDE FOR SHRINKAGE. THE MAIN POINT IS TO HAVE THE UPPER PART OF THE RISER LARGER THAN THE CONTACT AT CASTING. SEE THAT VENT IS PROVIDED FOR ENTRAPPED GAS. ENLARGE VENT IF NECESSARY. THE ARCH TOP OF THE BLIND RISER IS STRONGER THAN A FLAT TOP.

a riser. Note the heavy fillet at the juncture of riser and casting and the arched top which gives so much more strength than a smooth flat finish; also the vent that insures the riser itself being filled with metal.

27. Turning now to problems that although interesting to foundrymen, come, perhaps, more under the eyes of the metallurgist, we would like to state the problem as follows:

Required a metal to resist acid attack uniformly as long as possible but particularly not to be composed of areas for which the acid in question has a preference, or, to put it in other words, which will not develop preferential attack.

28. It is a common thought that composition is the great criterion for such a metal. The writer is not of this opinion, believing that the molecular and crystalline structure is of paramount importance. Of course, composition has to be considered, for example a high zinc brass is not expected to satisfactorily resist certain acids. By way of proof we would instance the tinless bronze or silicon bronze, Fig. 11. Both are of identical composition chemically but when subjected to acid attack the one is seen to eat away uniformly with a perfectly smooth close surface, whereas the other shows strong evidence of preferential attack.

29. When we ask why this should be, we find that it is due to uneven crystal formation due to lack of feeding, to absorption of gases during melting, or to too high a temperature of pouring. Any or all of these. Essentially we find the difference by fracturing the two metals—the close even grain of the one contrasting strongly with the uneven and discolored grain of the other. This

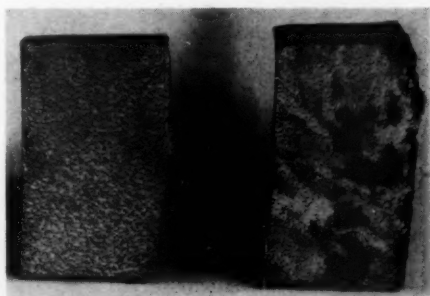


FIG. 11—DEEP ETCH SECTIONS OF TINLESS BRONZE OR SILICON BRONZE.

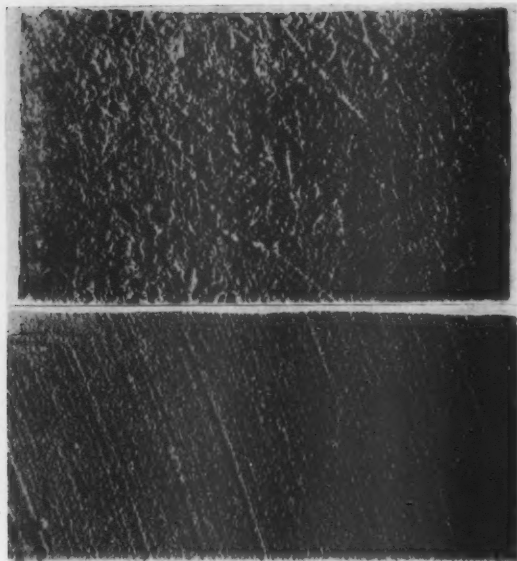


FIG. 12—COMPARISON OF CROSS SECTIONS OF BRONZE STICKS (85-5-5-5) POURED WITH DIFFERENT PRACTICES AND GATING METHODS.

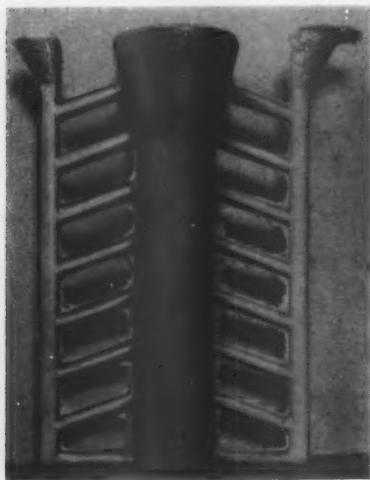


FIG. 13—GATING USED TO PRODUCE THE METAL SHOWN ON THE LOWER SIDE OF FIG. 12.

means that in making acid resisting castings the gating and feeding and pouring temperature are all important.

30. Remember deep etching must be used. Metal will give beautiful crystals on light etching, free from all sign of preferential attack which on continued etching will show up badly. By deep etching is meant putting the casting into a dish containing a solution of three parts of nitric acid, one of hydrochloric and one of water, all acids being commercial, and leaving it there for ten minutes. It is then removed and plunged immediately into cold water, finally washed under the tap, dried and painted with clear white shellac.

31. Fig. 12 shows complete cross-sections of a 3-in. diameter bronze stick 12 in. long, of the composition copper 85 per cent, tin 5 per cent, lead 5 per cent and zinc 5 per cent. Both sticks appeared entirely solid on machining or sawing. Fig. 12 (upper) was poured in the usual way from the bottom, hot metal being poured into the riser at the top. Fig. 12 (lower) was poured with eight gates entering each side as shown in Fig. 13. It was poured slowly from the bottom so that hot metal entered progressively and therefore the casting fed itself progressively. Note the uniformity of the acid attack in lower section of Fig. 12 and the preferential intercrystalline attack in upper section of Fig. 12. The whole of each bar was similar to the section shown.

32. For anti-corrosion service the feeding is still more important on account of the fact that it enables the crystal size to be uniform. The finer and more uniform the crystals the more uniform the corrosion attack. After all in many cases it is not a question of the metal not being attacked, but of the life of the metal under the conditions, and the more uniform the attack the longer the life.

33. For pressure castings feeding to avoid internal shrinkage is the important feature, the size of the crystals being secondary.

34. In the endeavor to get uniform small crystals a balance must be maintained between the *progressive* feeding of the casting as affected by the rate of pouring and temperature, and the feeding of the casting by the riser or risers. The old statement "the hotter the metal the better the casting" is not always correct. It is true that the hotter the metal the more chance the risers have of feeding the casting, but if the rate of pouring is adjusted,

and provision made for getting hot metal where feeding will be required, small risers will do the work and a finer crystal size in general be produced.

35. It is not enough to study the pouring temperature, the temperature of the metal as it traverses the intricacies of the mold must be thought out before the pouring temperature is finally decided upon. It must be remembered also that there are two factors that come into play, namely, the rate of entry of the metal into the mold and the temperature of the metal. If the former is increased the latter may be lowered, or, as is often preferable in the case of dross forming alloys, the rate of entry may be decreased and the mold filled completely by increasing the pouring temperature.

36. A statement has been made in connection with shrinkage that never seemed to be in accord with reasonable fundamental laws. The theory was that gravity pressure would make up for shrinkage and that it can be applied by putting a tall sprue in place of the usual short one on the casting. To investigate this two keel blocks, as shown in Fig. 4, were taken.

37. Both blocks were cast in oven dried sand molds and were filled with high tensile manganese bronze from the same pot at the same temperature. The top of the sprue in one case was of the same level as the top of the casting, in the other case the top of the sprue was four feet above the top of the casting. In other words, a pressure equivalent to four feet of metal was placed on the casting at the moment of pouring.

38. When the castings were removed from the sand the first one was found to have the usual enormous shrinkage cavity, almost large enough to place one's hand in, while the other had a perfectly level top with no shrinkage at all in evidence. This would seem to be the reason for the statement that the pressure gate would offset the shrinkage. The application of a chisel to the level surface, however, indicated a hollowness beneath and eventually a shrinkage cavity of equal size to the other casting was exposed. This is, of course, what we might reasonably expect for it is hard to conceive that anything else could happen. The metal enters the mold and is pressed up against the cope with a pressure equivalent to the four feet of height *above* the cope, however, almost immediately the metal at the junction of the sprue and casting freezes, thus cutting off the pressure, leaving the molten

metal in the casting itself free to cool under ordinary conditions, with the resultant shrinkage.

39. The level top is doubtless due to the fact that the first metal entering the mold had cooled considerably on its way down the long sprue and froze against the cope while the rest of the casting, being molten, gradually cools and recedes from the level top.

40. The fact that the use of a long sprue has little or no good effect on the casting is also attested by the data of tests of metal (Table 1) from the keel block having the 4 foot sprue and for the keel block having no extra height.

Table 1

	4 ft. Sprue	Normal Sprue
Yield Point (lbs. per sq. in.).....	43,950	44,450
Tensile Str. (lbs. per sq. in.).....	88,800	88,500
Elongation (per cent).....	23	23
Brinell No.....	156	156

FRACTURES

41. It was found that the use of the keel block, Fig. 4, to which references have been made already, is of great value in setting up standard metal conditions. To have the conditions standard in a series of plants one must avoid as much personal factor as possible. To this end the keel blocks are made in dry sand, that is of core sand dried in an oven with no blacking applied. The gate is made from a pattern so that the height of pour, the rate of feeding (the cross-section of the gate being constant) and rate of cooling are easily maintained.

(NOTE: The sprue used in Fig. 4 is the one condemned in upper sketch of Fig. 10 but in this particular case the block feeds the gate and the pull of the incorrect sprue is eliminated.)

42. One can then vary the casting temperature at will and it will be known that the test bars on the keel block have been perfectly fed and correctly cooled to give standard results. In the case of aluminum bronze, the keel block is quenched in cold water fifteen minutes after pouring, the pouring temperature being 1950° F.

43. The fracturing of the keel bar gives perhaps the greatest information to the metallurgist and the foundryman of any of the tests available. A collection of such fractures of different alloys for use in any foundry is of the greatest assistance to the

foundry superintendent as he can get his results long before any physical test bars or analyses are ready.

44. To fracture the keel bar it is sawn half way along the length of K, Fig. 4, whereupon a wedge is inserted and the half of the bar pried open. If desired one side bar can be used for tensile test, the other for Izod, as per Fig. 14, and the keel bar for compression and brinell. The shock or impact tensile test as also indicated in Fig. 14 is very useful. The Izod shock resistance test is one which is not used as much in connection with non-ferrous alloys as it should be.

METAL EXUDATIONS OR METAL SWEAT

45. Metal exudations or metal sweat is a problem frequently put up to metallurgists, particularly in connection with architectural bronze. It is frequently not realized to what extent a metal present in a very small percentage may become a large factor, owing to segregation. For example, an architectural bronze

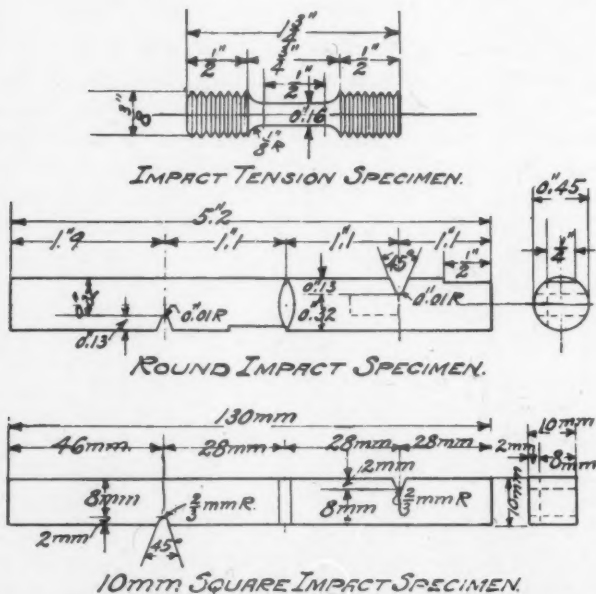


FIG. 14—IMPACT TEST SPECIMEN—TENSION—ROUND AND SQUARE CANTILEVER TYPE. FOR USE ON OLSEN COMBINED IMPACT—TENSION AND CANTILEVER TYPE IMPACT TEST.

of the composition 10 zinc, 5 tin, no lead and the balance copper, will sweat beads of metal of the composition 18 per cent tin and the balance copper, no zinc at all being present, while another alloy containing tin 4.4 per cent, zinc 9 per cent and lead 1.4 per cent, balance copper, will sweat metal which is pure lead free from either tin, zinc or copper.

46. Naturally discolorations produced by such sweating are inimical to architectural bronze that is required to have the natural metal finish without artificial coloration. The particular value of tinless or silicon bronze for architectural work lies in the absence of tin and lead which have a proclivity for sweating.

ENGINEERS

47. The following is particularly applicable to the engineers.

Test Bars

47a. One might perhaps start with the question of having test bars cast from the same pot of metal but separate from the castings. It has to be borne in mind that the real use of a test bar is to indicate to the engineer that the molten metal put into the casting was in thoroughly good condition, that is to say that it was *capable* of giving the necessary strength expected and that it was free from gas and oxidation. It is not the duty of a test bar to give to the engineer the strength of the various sections of the casting itself. This is a question that must be worked out as a matter of experience, based, if it is thought the work warrants it, on tests made on the various cross-sections of the actual casting itself.

48. Probably there have been more unfair rejections of castings on the basis of test bars when the same have been attached to castings than from any other cause. Sometimes the casting draws on the test bar and sometimes the test bar draws on the casting. This is not good for either.

Composition

49. Another question for engineers is the one that composition is of less importance than foundry practice. Frequently one will find that better castings are made, for example, with scrap metal mixed with the right proportion of metallurgical brains, than from virgin metal where the cerebral addition has not been made and also there is frequently a wide range of composition

if only the foundry practice involving proper melting and shrinkage provision is present.

The Why of Castings Breaking

50. Then comes the question of "why has this casting broken?" If the casting was not sound the answer is, of course, very easy and the engineer is entitled to say that the foundry practice was poor. On the other hand, hundreds of cases have come to our attention where the real answer to the question is that the casting broke because the metal was stressed beyond its ultimate strength. This is a clear bill of health to the foundry and comes back to one of two things, either that of the design or of the application of a greater force than was intended by the designer.

51. We have all seen the porter on the railway car endeavoring to open the car window, trying with his hands he fails and so he gets a long lever and pries up the window and is surprised to find that the handle breaks. The window handle was not intended to resist such multiplied force.

Relation of Design, Pattern and Final Casting

52. Let us for a moment go into the question of the relation between *design*, *pattern* and *final casting*. The engineer generally wants strength primarily, that is strength in the whole of any given casting. It is reasonable to assume that the useful strength is that point at which the relation between the actual strength of the casting and the maximum force it has to withstand bear the lowest ratio to each other. There may be parts in the casting that are actually weaker than such a point but which under the conditions have less strain put upon them.

53. In order that the engineer may attain his objective he must consider in his design the characteristics of the metal to be used and the practicability of producing a satisfactory casting in the foundry. This entails either a knowledge of such matters or consultation with those who have such knowledge. For instance in the matter of shrinkage characteristics of the alloy is *not* meant the shrinkage indicated on the patternmaker's rule, but the performance of the alloy where a heavy cross-section joins a light.

54. Other considerations such as the need of elimination from the casting of sharp angles and undercut projections, of the

limitations of the founding art concerning small diameter cores of considerable length, etc., etc., must receive attention if trouble to all concerned is to be avoided. The more consultations between the designing engineer, the patternmaker and the foundrymen, the better.

55. It is not uncommon for the patternmaker to be instructed to keep the machining allowance low in order to reduce the weight of the casting and therefore the intrinsic value thereof. In such manner is the door opened to false economy. It is true that the foundry replaces free of charge, that is free of *direct* charge, a faulty casting but the engineer is put to the expense and loss of time that the machining has required. A more generous machining allowance is in the end an economy of both time and money.

56. A custom that has nothing to recommend it is that of producing a pattern of improper foundry design and as the first foundry to which it is sent turns out a bad job, shopping around from foundry to foundry until some unlucky wight succeeds, more by good luck than good management, in obtaining *one* satisfactory casting. This immediately strengthens the purchasing agent's hand and he says to all the other foundries—"We got a good casting from A, therefore the pattern is all right." The fact of the matter is the pattern design was fundamentally wrong and although under a fortuitous combination of circumstances one good casting was obtained, it is no argument that the pattern was right. Had the pattern been right all reasonably good foundries would have been able to handle it.

57. Let us suppose that the casting has been properly designed, properly "patterned" and cast, it may still be spoiled by poor machining, either due to sharp angles or rough finish. Engineers of all people should appreciate the effect of these errors in connection with their stress concentration effect, the so common a cause of subsequent progressive fracture. Much has been said and doubtless much has been learned in this connection but every day brings examples of the continuation of these fundamental mistakes.

THE EXECUTIVE

58. The point of view of the executive is worthy of careful study but only a passing reference can be made here. Foundry executives should realize that there is need for some one in the

CANADIAN BRONZE COMPANY LIMITED

Physical Constants and Properties of Non-Ferrous Alloys

These figures are all the average results of actual tests on commercial quantities by Harold J. Roast, M.E.C., Lecturer in Metallurgy, Mc Gill University - May 1938.

[illegible]

FIG. 15—DATA SHEET OF CANADIAN BRONZE CO., LTD.

foundry to have time to "ponder." The word "ponder" is used because it implies "quiet thinking over a period of time." Provision for such a person in a foundry organization of any size is practically essential and, in fact, no matter how small the foundry, this pondering has to be done by somebody at some time, possibly in the *wee sma* hours.

59. There is also need for some one to collect data and to file it for intelligent use later—all of which emphasizes the fact that isolated experiments prove of comparatively little value to a company. The benefit is really obtained by the cumulative value of the work and to obtain this cumulative value proper records must, of course, be maintained.

60. In the company with which the writer is associated we have adopted the method of photographing problem castings from at least three and sometimes a greater number of angles, complete with gates and risers. These photographs are pasted on one page and the foundry procedure carefully typed out in detail on the other. In this way we get a complete and intelligent record of the steps used to obtain a satisfactory casting. Figs. 6, 7, and 8 are taken from this book. The data sheet, Fig. 15, is another example of compilation of data for future reference.

THE SALESMAN

61. Turning now to the salesman's point of view. From what has already been discussed, it should be apparent that price alone is a poor criterion upon which to base a selling argument, rather should the attitude be taken that the salesman's product is the result of superior knowledge of manufacture, honesty of purpose and economic production. It should be stated that the result of these components gives a certain price for the job in question, then the purchaser should have been so convinced of the sincerity of the salesman and the necessity of these components that the price is a matter of secondary consideration.

THE PURCHASER

62. Coming to the last but all important section of those engaged in the bronze business, namely the purchaser. Without the purchaser the whole structure falls to the ground, unless it be an institution engaged in research and not in stock dividends. The purchaser will frequently ask "When will the casting be

delivered?'' and the foundry superintendent will reply at such and such a time, *providing the casting comes out all right*. The purchaser immediately gets very annoyed and asks why the foundry does not know its job. There is good reason for the foundryman's replying as he did. Molding is an art rather than a science despite all the scientific aids which have been developed in recent years.

63. The superintendent's reply is reasonable because of the fact that after everything has been done that can be done, good metal having been used, the same being well melted, the mold being sound and the gating the best that is considered so for that particular casting, *then* molten metal is poured into the soft damp sand, (or dry friable sand) to rush over the fine sand edges, to create gas which must not be entrapped in the metal, to be chilled at one section and slowly cooled at another, with all the strains that this entails, and thus the work of hours or days is made or unmade in a few minutes. Verily, despite all man's care it rests at the critical last "On the Knees of the Gods."

64. It might well be said of the metallurgist, as has been so well said by Kipling in his lines entitled "THE SILENT SERVICE" if we substitute the metallurgist for the British navy—

*"Not in the camp their victory lies
Nor triumph in the market-place
For
They are men of little showing
But their work continueth
Broad and deep continueth
Greater than their knowing."*

DISCUSSION

Presiding . . . T. E. KIHLESEN, International Nickel Co., Bayonne, N. J.

MEMBER: Mr. Roast, on that 85-5-5-5 etching, was there any nickel content, or was it straight 85-5-5-5?

MR. ROAST: Straight 85 and three fives. There may have been some nickel. A trace of nickel is so easy to get in, but there was none intentionally added. If there was any, it must have been less than one-quarter of one per cent.

GEO. P. HALLIWELL¹: I should like to add a word of commendation to Mr. Roast's use of the deep acid etch. We have had used this test on

¹ Metallurgist, H. Kramer & Co., Chicago, Ill.

ingots to gain information as to the relative gas content of the metal. It has been our experience that when metal is sound, the surface etches uniformly. Every irregularity resulting from sawing is retained and the surface as a whole has a fine or close grained texture. If on the other hand the metal contains considerable gas, it will develop a non-uniform etch. Surface irregularities will be effaced and the metal will show an open or porous structure.

CHAIRMAN KIHLGREN: In connection with the deep etch test, I noticed Mr. Roast mentioned the lacquering of the sample to retain its present condition. There is a rather interesting sidelight on that. If you do not lacquer the material, then the acid gradually seeps out again from the pores and forms a green corrosion product wherever any porosity exists. If the metal is sound, no seepage occurs.

MR. ROAST: I should like the opportunity of replying to the point raised by Mr. Kihlgren. In the two specimens of metal, in connection with which the deep etching is under discussion, I would like to say that the sound specimen did not give any exudation of etching reagent even when completely dry. In the case of the unsound specimen, this was also dried before the application of lacquer and did not give any exudation or green corrosion. In this connection, however, it is only fair to say that the specimen was washed under full city pressure with water impinging into the porosities of the metal for quite some time, say at least ten minutes. If the wash is not extremely thorough and if it does not have behind it some considerable water pressure, there is no doubt that the etching solution will be retained by some of the porous areas, to come out at a later date. Both samples will, of course, oxidize if they are not lacquered but this is another point altogether.

CHAIRMAN KIHLGREN: I did not really intend to imply that the etched casting shown by Mr. Roast on the screen was unsound. I did wish to point out, however, that a measure of porosity can be obtained in bronze castings by etching the section to be examined, washing, drying and permitting to stand about unlacquered for a period of time. If the casting is unsound, acid will seep out of the interdendritic voids and form a green corrosion product on the surface. If sound, no such seepage will occur and the etched surface will be free of deposited salts.

Founding of Pressure Castings*

By H. H. JUDSON,** SENECA FALLS, N. Y.

Abstract

In this paper, the author outlines the practice for the production of pressure castings in the shop of which he has charge. In this shop, many castings are made which must resist pressures of 1500 lb. per sq. in. on such searching fluids as gasoline and oils. Two distinct types of iron are used in this foundry, one containing various percentages of steel rails and the other no steel whatsoever. The first type of iron is used in castings which must withstand 500 lb. per sq. in. pressures or greater. The second type is used in castings which must withstand pressures not more than 200 lb. per sq. in. Those castings between these pressures may require either type of iron. For high-test iron pressure castings, the author uses what he terms the two-cupola process, which he describes in detail, giving charges, blast pressures, materials, analyses of both charged materials and final product. He also outlines the basic thoughts that led to the adoption of this process, gives information on the gating and risering of pressure castings and the use of denseners and chaplets. The author prefers, in fact demands, hot-pouring and explains his reasons for that practice. The author's investigation of the two-cupola process also led to improvements in his practice used in single units. He outlines his present practice in cupola operation and ends his paper with a discussion of the procedure followed in his shop for the remedy of internal defects in castings.

1. Generally speaking, engineering gray iron castings can be divided into two broad classifications, namely, structural castings and pressure castings. The structural casting field covers those parts of apparatus which serve as frames, foundations or beds. Examples of that class are motor and generator frames, pump and engine frames, bedplates, gear and transmission casings. The field

* This paper originally was presented as the 1936 exchange paper of A.F.A. to the Institute of British Foundrymen.

** Foundry Superintendent, Goulds Pumps Inc.

NOTE: Paper presented before Gray Iron Session of 41st Annual Convention, Milwaukee, Wis., May 4, 1937.

of pressure castings includes those, which in operation, are subjected to internal pressures such as hydraulic pump cylinders and casings, pipes, valve boxes and pressure fittings.

2. Structural castings are designed from a mass and rigidity standpoint. Provision of sufficient iron to satisfy the mass or inertia requirements automatically meets rigidity and strength requirements. Iron used in that type of casting need not be of such an analysis that, throughout any one casting, a close-grained homogeneous metallic structure exists.

3. An open-grained structure in the center of chunky sections is not detrimental. There are exceptions to this thought, noticeably machine tool beds and frames, but by and large, structural castings do not depend upon freedom from internal-draws, spongy spots, coarse graphitic carbon, and upon a dense fine-grained structure for their efficiency and utilitarian aspect.

4. On the other hand, pressure castings are quite dependent upon absence of draws, shrinks, spongy spots, coarse graphitic carbon and demand a dense, fine-grained homogeneous structure to be serviceable. Structure of the iron, as for instance, the amount of graphitic carbon present and, more vital still, the condition in which this graphite exists, is all important in castings subjected to pressure.

USES TWO MIXTURES

5. Two distinct types of iron mixtures are used in the author's foundry. The first type, in the high test iron class, is that in which various percentages of steel rails form the major part of the charge, the remainder being pig iron and spiegeleisen. The second type contains no steel of any kind, the charges being made up entirely of pig iron and scrap.

6. Returns from the steel mix, or high test irons are used in the pig iron-scrap mixtures for bedplates and frame parts. The first type of iron is used in all castings which are subjected to pressures above 500 lb. per sq. in. It also is used in large size low pressure pumps. Operating pressures of these pumps may be low but the over-all load on large unsupported sections sections may be such that a strong iron is required.

7. Pressure tightness is of primary importance while ease of machining is secondary. The pig-scrap mixture is used for parts in the small hand and power pumps in which the operating pressures do not exceed 200 lb. per sq. in. Machinability is of equal importance with pressure tightness in this class of work.

Castings for pumps which operate at pressures between 200 and 500 lb. per sq. in. may or may not require a high test iron.

8. The small sizes in this range are amply strong because of low over-all loads and metal sections are light enough so that the cooling rate is sufficiently rapid to insure good snug iron. Larger sizes in this range usually require a high test iron. Machinability is not likely to be so important, in this class, as pressure tightness can be a problem.

9. That part of our line which requires iron mixtures in which steel rails are used will be described first. All of our thoughts concerning the founding of pressure castings, in which steel rails form a part of the cupola charges, date back to 1926 to the inception of the two-cupola process for making high test iron pressure castings in our foundry. A brief description of this process, our experience with it, and the thoughts behind it follows:

TWO CUPOLAS USED

10. Two cupolas, one with a 54-in. bore and the other with a 72-in. bore, are used to produce a high test iron. The 54-in. cupola is used to melt charges of the following composition: 1400 lb. steel rails, 4 in. or larger; 135 lb. pig iron, 15 per cent silicon; and 85 lb. spiegeleisen, 20 per cent manganese. Tuyeres in this cupola are set 6 to 7 in. above the sand bottom. The bed height when charging is begun, is 34 in. above the top of the single row of tuyeres.

11. The cupola stands fully charged for $1\frac{1}{2}$ hours before the blast is put on. Coke splits are 180 lb. each and the blast volume is kept at about 5500 cu. ft. per min. with 12 to 16 oz. blast pressure. The tap is run continuously. The spout is of the skimming type. All of this iron is tapped into one ladle and will average about the following analysis: Silicon, 1.35 per cent; sulphur, 0.11 per cent; manganese, 1.00 per cent; phosphorus, 0.13 per cent and total carbon, 2.40 per cent.

12. Meanwhile, the 72-in. cupola is melting a soft iron of the following analysis, for regular production work, the burden consisting of pig and scrap iron: Silicon, 2.40 per cent; sulphur, 0.10 per cent; Manganese, 0.55 per cent; phosphorus, 0.35 per cent, and total carbon, 3.25 per cent. A predetermined amount of this soft mixture is run into a crane ladle, suspended from a crane scale, and then is dumped into the ladle containing the hard iron from the 54-in. cupola.

13. The resulting analysis of this mixture on the basis of 4

tons of hard iron to 1 ton of soft iron runs about as follows: Silicon, 1.50 to 1.70 per cent; sulphur, 0.11 to 0.13 per cent; manganese, 0.90 to 1.10 per cent; phosphorus, 0.15 per cent, and total carbon, 2.50 to 2.65 per cent. This iron is used for castings that operate at pressures up to 1500 lb. per sq. in. on oil and gasoline, and which are tested up to 3500 lb. per sq. in.

14. These castings weigh from 500 up to 3000 lb. Wall thickness of the cylinders, valve boxes and piping details, average

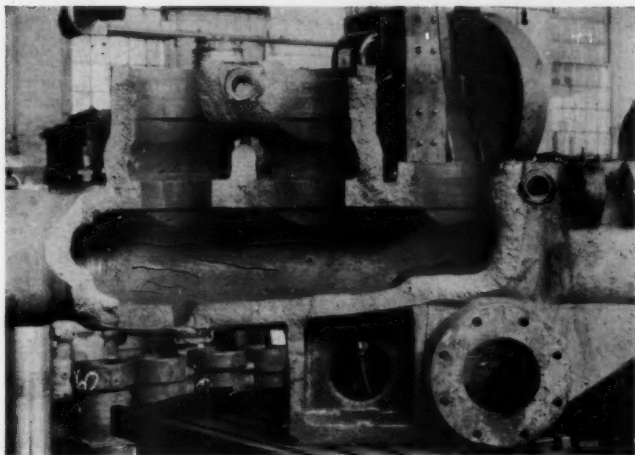


FIG. 1—LINE PUMP CYLINDER WEIGHING 2300 POUNDS, TESTED TO DESTRUCTION AT 6000 POUNDS PER SQUARE INCH PRESSURE.

from 2 to $2\frac{1}{2}$ in., with valve deck sections as thick as 3 and 4 in. Like other irons of this type it shows a markedly uniform structure across a fracture. Fig. 1 shows a cylinder, weighing 2300 lb. that was tested to destruction, failing at 6000 lb. per sq. in. pressure.

MICROSTRUCTURES

15. Fig. 2 shows the structure of this iron at 100 diameters, etched. Fig. 3 is the same specimen at 500 diameters. Tensile strength, taken from test specimens cut from the walls of actual castings, runs from 40,000 to 48,000 lb. per sq. in. Brinell hardness varies from 207 to 217. A standard $1\frac{1}{4}$ -in. diameter test bar is gray throughout and castings as thin as 1 in. in wall section are quite readily machinable.

16. If there is any white iron in the fracture of the $1\frac{1}{4}$ -in.



FIG. 2—TWO-CUPOLA IRON AT 100 DIAMETERS, ETCHED.

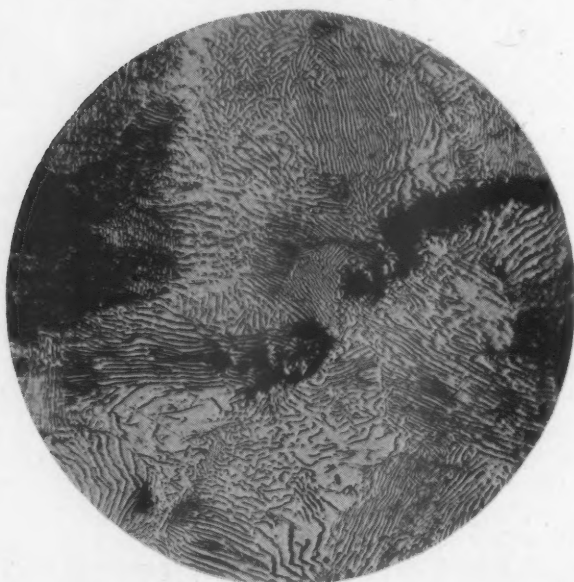


FIG. 3—TWO-CUPOLA IRON AT 500 DIAMETER, ETCHED.

bar it is a definite indication that the iron is off. Two heats were made, accidentally, with silicon at 1.23 per cent and 1.28 per cent. The iron was lifeless, freezing on the lip of the ladle, and showed a white network in the fracture of the arbitration bar. We then found that more than a charge of 15 per cent silicon pig had remained in the drop, which accounted for the low silicon.

17. A return to the charging scheme that would insure bringing all of this silicon down into the ladle eliminated the trouble. Thus we feel that 1.40 per cent silicon is the lower limit for an iron running 2.50 to 2.70 per cent total carbon. Silicon, in the cupola charge, is a splendid deoxidizer, and exerts a softening effect through preventing excessive oxidation.

SHOWS WHITE FRACTURE

18. In an attempt to force carbon still lower than 2.50 per cent, a heat was run with bed and coke splits lower than standard, but with regular blast volume and charges. Carbon dropped to 2.34 per cent and silicon to 1.39 per cent, with manganese at 0.77 per cent. The heat was a total loss and melting conditions were such that iron actually was burned in the cupola. The charging door resembled a huge fire-works sparkler.

19. The iron was lifeless, shrunk badly and showed a dead white fracture in a 2-in. diameter pouring sprue. Strangely enough, this sprue was machined readily with high speed steel; a tensile piece cut and threaded from it failed at 46,440 lb. per sq. in. We feel that with our method, the low limit of carbon is 2.40 per cent, as we have had successful heats with the total carbon just under 2.50 per cent.

20. Considerable relief from rejections, because of leaks, internal draws and shrinkage on high pressure parts and also from low bursting pressures has been had from the use of the two-cupola iron. This is true to such an extent that the process and thoughts connected with it have influenced our practice with the high test irons melted in one cupola. Attempts were made to produce a similar iron in one cupola, the 54-in., but with varying degrees of success. The same materials were used, but a charge of soft iron equivalent to that which would ordinarily be added in the molten condition was added to the steel-mix charges. These additions were made in several different ways but results were never up to standard.

21. Heavy-walled high pressure castings were likely to

sweat at test pressures at 1000 lb. per sq. in. and up, at points where fins or flash had been chipped off, indicating a coarser structure. Graphite was coarser as shown by micrographs.

22. The basic thoughts, as we see them, in the two-cupola process are as follows:

(1) Materials charged into the 54-in. cupola are almost entirely free of carbon in the graphitic form. Carbon content of the charges is low. These conditions, coupled with others, make for a finely divided graphite.

(2) The iron has a low carbon content, which is conducive to high strength, early freezing and a uniformly fine-grained structure.

(3) Best results always have been obtained when this iron has been melted hot and poured as hot as possible. The hotter a cupola-melted iron is poured the quicker and more uniformly it cools through the freezing range.

23. This molten hard iron partakes of the virtues of a superheated iron. However, it is too hard for any of our castings, and has a high shrinkage, with little or no graphitization. This hard iron properly melted, has plenty of molten life, as sandblast nozzles and sandslinger tips are cast from it with no trouble from misruns. The soft iron added provides the softening elements necessary, that is, the graphite nuclei and some silicon.

DIFFERENCE IN GRAPHITE STRUCTURE

24. Incidentally, to retain the benefits of a superheated iron, soft iron is added to the hard iron as late as possible in the process so that the graphite structure will not be coarse. We think this is so, because of an experience we had four years ago. Since this high test iron is poured quite hot, it punishes the dry sand molds and cores severely. The iron was held, to cool it down, for 20 minutes before pouring, on two successive days.

25. Cylinders from both heats burst at ordinary testing pressures. Tensile specimens were cut from the walls of the cylinders and were tested. There was a decrease of from 12,000 to 15,000 lb. per sq. in. in strength, as they broke at 32,000 to 35,000 lb. per sq. in. Chemical analyses were quite what they should be. However, a microscopic examination at 50 diameters showed a vast difference in the graphite structure.

26. Graphite in the dull-poured iron was very coarse which, to our mind, accounted for the drop in strength. Fig. 4 shows the

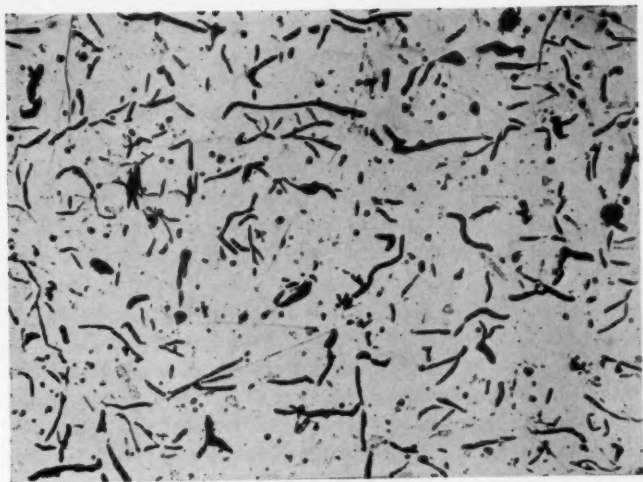


FIG. 4—CYLINDER IRON POURED HOT, 50 DIAMETERS, UNETCHED.

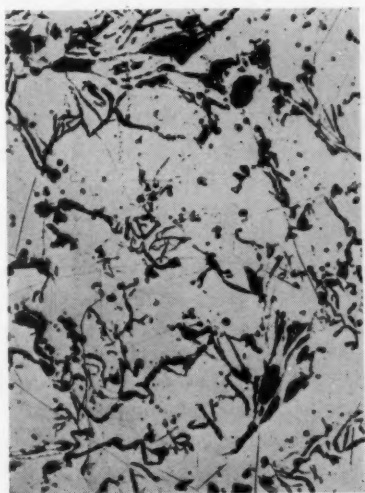


FIG. 5—CYLINDER IRON POURED DULL, 50 DIAMETERS, UNETCHED.

graphite, at 50 diameters, of a satisfactory iron. The sample was taken from the 2-in. wall of a cylinder, poured as hot as possible.

27. Fig. 5 shows the graphite, at 50 diameters, in a sample taken from the same location as Fig. 4, only from a cylinder poured on the dull side. The iron had been melted hot but was cooled down in the ladle. Then an examination of the fracture with a low powered magnifying glass, 3 or 4 diameters, showed small rounded dark gray patches in a normal silvery gray matrix.

28. Hence, we add the soft iron to the hard iron not more than 5 minutes before pouring is begun. The mixture then is poured promptly with as little reduction in temperature as possible. An optical pyrometer reading indicates an apparent temperature of about 2550° F., or actual temperature around 2700 to 2750° F. at the spout of the hard iron cupola.

29. We believe from actual experience that low total carbon, from 2.40 to 3.00 per cent, is desirable in unalloyed iron, for high pressure work. It promotes a fine-grained structure both as to matrix and graphite, so necessary for pressure-tightness and strength, if poured between 2600 and 2700° F. actual temperatures. This we admit is about as hot as we can melt in a cupola.

30. It makes for uniformity of structure in varying wall sections, as judged from examination of the fractures of several hundred heavy walled cylinders. Its freezing range is such that, with proper risering, shrinkage and spongy spots are readily avoided. When sections do not exceed 2 in. in thickness risers can be eliminated.

RISERS MUST BE LARGE

31. If risers are used, they must be large enough to feed the casting without pumping or churning with a rod. Churning feeding heads in low carbon iron mixtures in our experience is actually harmful. The juncture of the riser with the casting always showed large open shrink holes. Incidentally, we learned several years ago that the use of chills or denseners, as well as chaplets and anchors on low carbon iron castings is bad.

32. Even though the denseners used on internal cores in a large cylinder were quite light as compared to the wall section against which they were used, a fine hair line chill was formed on the inside. This reduced the bursting pressure of the cylinders tremendously. An improvement in melting conditions removed need for risers, and use of chills. Chaplets and core anchors are apt to produce blowholes in castings.

33. Evidently the metal begins to freeze at such a high temperature and to develop the mushy state so soon in the cooling cycle that gas formed, when the iron strikes the cold chaplets, is not released by the metal. It is our practice to bolt all cores down or hang them in the cope. It is only on non-pressure sections of castings and un-machined parts where anchors and chaplets are used.

34. Any fluttering of the iron against mold or core is bad for low carbon cast irons. Gas formed usually is trapped in the casting. So all core sand and molding sand mixtures must be open and free-venting. Several so-called shrinkage problems were solved by use of a vent wire.

35. The second basic thought in connection with the two-cupola process deals with low total carbon content. Lowering of total carbon is brought about in the cupola by use of steel rails in the charges which are melted under the following conditions:

36. A low bed is used so that molten iron has less coke through which to pass and absorb carbon. Incidentally, there may be a slight tendency towards an oxidizing condition with a low bed, which makes for a reduction in carbon in any mixture. By-product coke used is a very dense grade. The analysis of which is: Volatile matter, 0.90 per cent; fixed carbon, 91.5 per cent; ash, 7.7 per cent, and sulphur 0.58 per cent.

USES SLOW-BURNING COKE

37. It is slow burning and holds up well. Coke charges are low compared to other papers written on the subject of melting a high steel charge in the cupola. Blast used is normal. Evidently, this dense slow burning coke, coupled with the blast used, maintains the bed at a low point, without dropping it too low. In our pig iron-scrap iron mixtures we have noticed a definite drop in the total carbon content. For years it ran close to 3.50 per cent, when using a bee-hive coke. Since we have used a by-product coke the carbon has gradually dropped, to between 3.25 and 3.30 per cent.

38. We tried three different brands of by-product coke, each succeeding brand denser (heavier per unit volume) than the preceding. Each change brought with it a lowering of total carbon. The present coke is the densest and gives the lowest carbon, possibly because we can and do use less of it per charge, by weight, than any of the others. So the grade of coke as well as the bed height affects the total carbon.

39. Tuyeres are set close to the sand bottom; 6 to 7 inches above it. Thus the amount of coke below the tuyeres is held to a minimum, and the iron has still less coke through which to pass. Because the tuyeres are set so close to the bottom the tap must run continuously. As fast as the iron melts it is withdrawn from the cupola and also from the carbonizing influences of coke in the well of the cupola. The iron spout is of the skimming type, for the removal of slag.

40. The third basic thought is that pertaining to pouring temperature. Incidentally, what follows covers pouring practice used on our entire line of pressure castings. All low carbon high test iron castings are poured as hot as possible. No time is lost between tapping out and pouring the molds. It is our belief that the hotter cupola-melted metal is poured, the finer and more uniform the grain structure and the greater the freedom from internal defects and chilled corners.

41. Most investigational work on the effect of superheating cast iron on its physical properties has been done in the electric furnace. Temperatures reached in the experiments are much higher than those obtained in a cupola. We pour at about 2650° F. actual temperature.

42. This is close to the best pouring temperatures for superheated electric furnace irons, for an electric furnace iron superheated to 2800 and 2900° F. will give its best physicals at a pouring temperature between 2600 and 2700° F. So starting off with a cupola-melted iron in which the carbon is quite all dissolved and at a temperature around 2700° F., some of the benefits of an electric furnace refined iron are had.

HOT IRON IS ESSENTIAL

43. There was a period, several years ago in our shop, during which all castings, large and small, for heavy pressures and light pressures, cast in green sand and dry sand, were poured on the dull side. If the metal was hot it was chilled down by adding scrap to the ladle. Then with no other changes, as far as iron mixture, sand, molding, gating, etc. are concerned, there followed a period during which all molds, both green and dry sand, were poured as hot as the iron could be got to them. The machine shop losses from leakers, dirt, shrink and spongy spots, dropped so suddenly that it served as conclusive proof that hot pouring is essential to pressure tight castings. The improvement in the machine shop was so marked that hot pouring is required.

44. Professor G. B. Upton, in his book, "*Materials of Construction*" notes that: "If the metal is poured *cold*, the outer part of the casting cools sharply, in heating up the mold, and the center cools very slowly during freezing. If the metal is poured *hot*, the mold will be thoroughly heated long before freezing, and the piece will be cooling rapidly throughout during freezing."

45. Reference to cooling rate curves of steels quenched in various liquids shows that the thought behind the previous statement is that an appreciable length of time has passed, after pouring, before establishment of the temperature gradient that governs the cooling rate of the casting, especially the rate through freezing. Dull pouring, that is pouring near the freezing temperature, brings about a quick freezing of the skin of the casting, by heating up the cold mold, but does not provide the necessary temperature difference between metal and mold to establish a steep temperature gradient when freezing is approached. Thus the interior of the casting cools relatively slowly. On the other hand, pouring hot heats up the mold and only a slight skin is formed, leaving the interior still molten and at a sufficiently high temperature so that when the freezing temperature is approached a steep temperature gradient already has been established and relatively rapid freezing occurs.

COOLING TIME-TEMPERATURE RELATIONSHIPS

46. Figs. 6 and 7 represent, schematically only, the time-temperature relationships in the cooling of two similar castings, one poured dull and one poured hot, from the same ladle of iron. These curves are typical of cooling curves of quenched steels. The skin temperature drops rapidly through the freezing range and beyond. The center does not decrease in temperature at the start. However, this decrease in skin temperature soon sets up a temperature gradient between the skin and the center. The skin then begins to draw heat from the center, and the drop in temperature of the skin to the mold is retarded. The center now is cooling and increasingly greater cooling rates are being established as the time interval after pouring increases.

47. Consider the dull poured casting, Fig. 6. The casting is poured just above the freezing range. So before sufficient time has elapsed to permit the development of a rapid cooling rate, the casting has begun to freeze. The skin has already passed through the freezing range at a rapid rate, and therefore shows a fine

grained structure. The curve representing the casting halfway between the center and the skin indicates that the casting is cooling less slowly through the freezing range and will show a coarser structure than the skin. The center is cooling still more slowly through the freezing range and will have a still coarser structure.

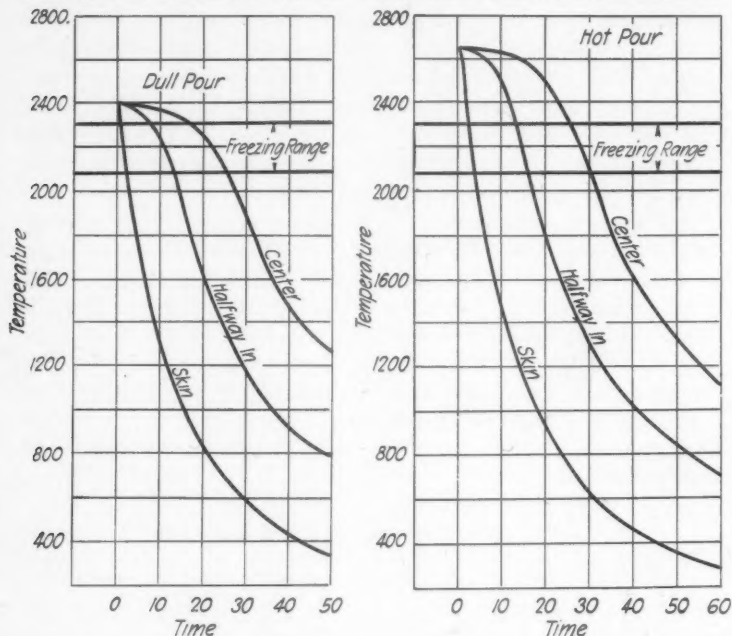


FIG. 6 (LEFT)—TIME-TEMPERATURE RELATIONSHIP OF THE COOLING OF A CASTING Poured WITH DULL IRON. FIG. 7 (RIGHT)—RELATION OF TIME AND TEMPERATURE IN COOLING OF A CASTING Poured WITH HOT IRON.

There has not been sufficient time for the casting to set up a steep temperature gradient in the freezing range so the result is slow freezing and coarse graphite.

48. Fig. 7 represents a similar casting poured hot. The skin freezes rapidly at the start but not as rapidly nor as deeply as in the dull pour. Then the center section begins to feel the effects of the decrease in skin temperature and it begins to cool also. This beginning of the center to cool occurs high enough above the freezing range to permit of the establishment of a steep temperature gradient so that, as the freezing range is approached, the maximum rate of cooling has been established clear to the center

of the piece. Hence, relatively more rapid freezing of the center of the casting occurs, resulting in a finer grained structure.

COOLING RATES ARE UNIFORM

49. Reference to both curves, Figs. 6 and 7, shows that in the hot pour, the cooling rates inside the piece are not only faster but they are more nearly uniform than in the dull pour. Fig. 8 shows schematically, the relative cooling rates of the various sec-

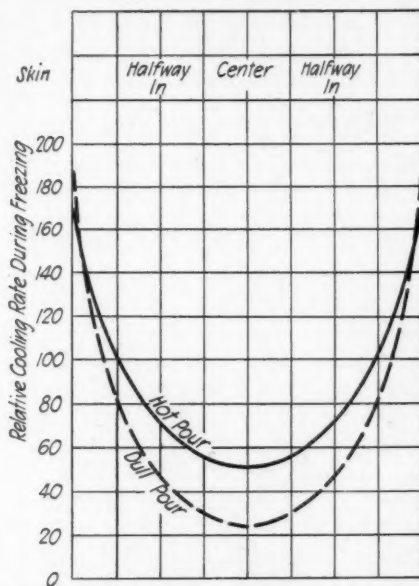


FIG. 8—COOLING RATES OF CASTINGS POURED WITH DULL AND HOT IRONS THROUGH SAME FREEZING RANGE.

tions of the hot and dull poured castings, in the freezing range. The cooling rates are merely numbers representing the slope of the cooling rate curves of Fig. 6 and Fig. 7 in the freezing range. The greater uniformity of the cooling rates in the hot pour over the dull pour is noticeable, as are the faster cooling rates.

50. The practical demonstration of those views on effects of pouring temperature on rate of cooling in castings is shown in the quenching of steel. Given two pieces of steel, identical analyses, one of which is $\frac{1}{2}$ -inch diameter and the other 3 inches diameter, to be hardened. The $\frac{1}{2}$ -inch piece can be quenched just above the

critical temperature and it will be hard throughout because the cooling rate of this small piece is fast enough. The 3 inches diameter piece must be heated to a much higher temperature before quenching so that the time necessary to develop the required speed of cooling for the hardness to extend throughout the piece is available otherwise the center will not be hardened.

51. Practical experience has shown that results bear out that theory, at least, for the cast irons melted in the cupola. Since the rate of freezing affects both the amount and size of the graphite particles and since hot-pouring will cause rapid freezing, which in turn makes for a fine grained structure, all of our pressure castings are poured on the hot side.

PROMOTED COARSE GRAPHITIZATION

52. We refer again to the experience which we had of holding iron in the ladle to cool it down. Adding the soft iron to the hard iron provided the graphite nuclei necessary to promote coarse, graphitization. Holding the mixture provided ample time for any agglomeration of the graphite that might take place and brought about the low pouring temperature. We feel that the one-cupola process produces nonuniform results because the soft iron, both in the solid and liquid forms, carries graphitic carbon into the mixture too early in the process. If this soft iron could be obtained in the chilled form (that is, with the carbon mostly in the combined form in the pig) we would get better results.

53. As was stated at the beginning of this article the good results obtained with the two-cupola, low-carbon iron led us to consider our common one-cupola steel-mixes. These one-cupola steel-mixes, charged in the cupola first and therefore tapped out first, to avoid as far as possible the mixing with the soft iron charges which follow, are used in pump parts which operate at pressures between 200 and 1000 lb. per sq. in.

54. Charges for the steel-mix irons, or high test irons, melted all in one cupola, contain from 30 to 60 per cent steel rails, 3 per cent spiegeleisen and the remainder pig iron, one of which contains 2.25 per cent silicon and the other 3.50 per cent silicon. No scrap, of any kind is used. The amount of steel used is governed by the wall thickness of the castings to be poured. The thicker the wall section the lower the total carbon and therefore, the more steel rails per charge. This particular arrangement works out quite satisfactorily in our plant where it is applied to castings up to 2 in. thick.

55. The silicon content, determined by the pig iron used, is governed also by the wall thickness, from the machinability standpoint. The total carbons of the various mixtures vary between 2.80 and 3.25 per cent, and the silicon content between 1.50 and 2.00 per cent. The machinability of a ladle of iron for the particular jobs to be cast is determined by the depth of chill in a small bar, 1 x 2 x 6 inches, cast open sand against a chill bar. The thicker the wall section the greater the depth of chill that is desired.

56. Formerly the various depths of chill were obtained by using a fixed steel percentage in the charge and varying the silicon content. In other words, the total carbon was reduced to a more or less fixed point, by using the same amount of steel rails in each charge, while the silicon was varied. When a deep chill was wanted the silicon was lowered and when a light chill was wanted the silicon was raised.

LEAKERS WERE DEFINITELY HIGHER

57. One objection to this system, was that the chill tests were likely to be erratic. The low silicon mixtures, intended for deep chills and therefore, heavy walled castings, were likely to give trouble. The machine shop would report certain castings as being hard, and they were very hard, even though the chill test for that particular ladle indicated that the analysis was about right. The leakers also were definitely higher at that time.

58. The present method is to vary both the silicon, which is about 50 points higher than formerly, and the total carbon. The chill tests run much truer to form with these mixtures. Experience has shown that the heavy walled castings from 1½ up to 2 in. thick, give best results on the pressure tests at 1000 lb. per sq. in. when the total carbon ranges from 2.80 to 2.95 per cent. The silicon then is held at 1.50 to 1.80 per cent. Incidentally, our experience checks closely with that of others, that the lower carbon cast irons are not affected as to unit strength and grain size by rather appreciable variations in silicon.

59. In the two-cupola process the silicon has run as high as 1.80 per cent, when our standard has been 1.50 per cent without any apparent ill effects from softness and excessive graphitization. Decreasing the total carbon content of an iron mixture, everything else being equal, tends toward making the iron freeze as white iron. However, raising the silicon, in the lower carbon iron offsets

this tendency. Incidentally, the ferrite formed is stronger because of the increase in silicon.

60. Fig. 9 shows an 8-stage centrifugal pump now operating at 1000 lb. per sq. in. on gasoline. The lower half casing weighs 2000 lb. and the upper half weighs 1400 lb. The analysis of the iron in these castings is 1.65 to 1.80 per cent silicon; 0.12 per cent

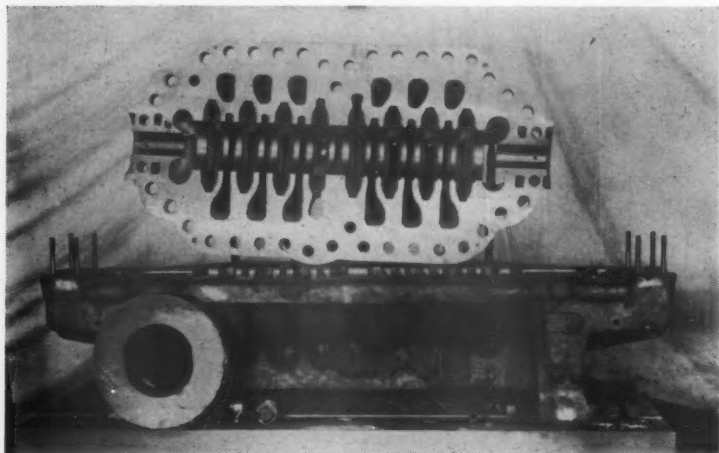


FIG. 9—SIX-INCH, 8-STAGE CENTRIFUGAL PUMP CASING OPERATING AT 1000 POUNDS PER SQUARE INCH PRESSURE ON GASOLINE.

sulphur; 1.04 per cent manganese; 0.15 per cent phosphorus, and 2.90 to 3.00 per cent total carbon.

61. They do not leak when tested with kerosene at 1600 lb. per sq. in. pressure. They are operated at 1000 lb. per sq. in. on oil and gasoline so they must be quite free from internal defects of all kinds. The heavy parting flanges are $2\frac{1}{2}$ in. thick, as cast, the wall thickness of the volutes is $1\frac{1}{8}$ in. and the partitions between the various stages are $11/16$ -in. thick, as cast. The cored passages are intricate and the sections vary abruptly all through the casting.

62. As the wall sections decrease in thickness, the total carbon is increased by decreasing the percentage of steel rails per charge. The silicon may or may not be increased, depending upon the amount the total carbon is reduced. Castings measuring $\frac{3}{4}$ -in. thick and tested at 500 lb. per sq. in. are made from iron analyzing

3.00 to 3.20 per cent total carbon and silicon between 1.85 and 1.90 per cent. Small parts, that are from $\frac{1}{2}$ to $\frac{3}{4}$ -in. in section, are poured with a mixture analyzing 3.15 to 3.25 per cent total carbon and 1.90 to 2.00 per cent silicon.

SILICON CONTENT IS INCREASED.

63. Compared to our practice of 7 or 8 years ago, our present high test iron practice calls for mixtures in which the silicon contents range from 40 to 60 points higher and the total carbon from 25 to 75 points lower. Our thoughts behind the use of higher silicon in the low carbon cupola mixes are that it can serve as a deoxidizer in the melt and also prevents the low carbon irons from freezing out white.

64. Some experiments were run recently with all scrap mixtures in a 30-inch cupola. Silicon was added to the charge in the form of cement briquettes during one series. In the next heat a comparable amount of silicon in the form of lump and powdered 90 per cent ferro-silicon was added to the ladle. The iron was cast in chill molds. The analyses from the two heats showed: Briquettes in cupola—2.20 per cent silicon; 0.34 per cent combined carbon, and 3.40 per cent total carbon. Ferrosilicon (90 per cent) to ladle—2.15 per cent silicon; 1.07 per cent combined carbon, and 3.32 per cent total carbon.

65. The results were doubted and checks were made which were substantially the same as the original. Evidently the addition of silicon to the charge is more potent as a graphitizer, possibly because of its deoxidizing qualities. We feel that if the total carbon is lowered so that the silicon can be run at say, 1.75 per cent, instead of 1.25 per cent, the iron is benefited by the presence of this higher silicon in the charge.

66. So far this discussion has dealt entirely with steel rail-pig iron mixtures. The other type of iron used in our foundry is that in which no steel rails are used at all, being a mixture of pig iron and scrap iron. The analysis which has been followed for years is as follows; 2.30 to 2.50 per cent silicon; 0.09 to 0.11 per cent sulphur; 0.50 to 0.60 per cent manganese; 0.25 to 0.45 per cent phosphorus, and 3.30 to 3.50 per cent total carbon.

67. This analysis is a common one for the general run of small and medium castings. Reference already has been made to the decrease in the total carbon of that particular mixture during the past 2 or 3 years.

68. One thought that stands out above all others in connection with this mixture when used on pressure work is it gives the best results when it is melted hot and poured hot. Every attempt to economize on coke, both as to quality and quantity used has resulted in low spout temperatures, more shrinks and draws in the castings and more leakers in the test floors in the machine shops. Invariably, a heat, in which there has been a dull period, is followed by an increase in defectives due to draws or shrinks, at points which are prone to shrink.

PREVENTS SHRINKS AND DRAWS

69. Internal defects and shrinkage may be the biggest source of trouble in a foundry, called upon to cast pressure work. There are six basic ideas followed in our shop to combat shrinks, draws, and internal sponginess in the castings, which are poured from this soft iron mix. The ideas and the order in which we use them follow:

1. The internal defect commonly called shrinkage, may be caused by gas from the mold or core. Whenever shrinkage is mentioned we think of two things: (a) Permeability of the molding and core sands, and (b) Venting of the molds and cores. Innumerable shrinkage troubles have been eliminated through the use of additional vents in the molds and cores. One rather simple job returned 25 per cent loss in leakers. Regardless of the gating practice, the iron mixtures used, etc., the leakers continued. The venting of 3 small pockets in the cores eliminated the trouble and the loss dropped below 1 per cent. Impellers for centrifugal pumps developed shrinks and spongy spots on the hubs and wearing rings. A very fine sand was used in the core to insure smooth water ways, for high efficiency. Change to a very coarse open sand and a special core oil which enabled us to use an oil-sand ratio of 1 to 80, provided a free venting core which removed the shrinks. The smooth surface in the rough core was obtained by a high grade plumbago wash. So we look to the venting of the molds and cores first whenever shrinkage shows up in a run of castings.

2. If venting does not cure the trouble we experiment with the gates. We place the ingate so that the point at which the shrinkage takes place will get comparatively dull metal, that is gate as far from the seat of shrink trouble as possible. Usually the ingate is made as small as will run the casting.

Thus feeding is going on while the casting is being run. Part of the runner which connects the down sprue with the ingate always is placed in the cope, to provide a means of ridding the iron of any slag or loose sand.

3. If that gating fails then the ingates may be placed near the chunky part that shrinks and increased in size. Possibly the runner is increased as well as the down sprue. A strainer core then is placed in the pouring basin at the top of the cope to serve both as a choke for slow pouring and to keep the basin full to prevent slag and dirt from being carried into the mold. As soon as the mold is full the sprue now acts as a feeding head. If the strainer core is set in the joint of the mold, the sprue shuts off quickly so does not serve as a feeder. The runner and ingate may be enlarged as stated, to further the feeding effect of the sprue.

4. If these methods fail, a riser is used. The riser and the opening from it to the casting are made as large as the casting will permit so that feeding takes place until the casting is set. Quite often the use of a riser with this soft grade of iron makes for a coarse open grained structure where the riser attaches.

5. If that is so then chills are used, but no risers. The use of chills or denseners is never a complete cure, but considerable relief may be had from their use.

6. If all of the previously described measures fail on any one job, we discontinue casting them in soft iron and use a high test iron analyzing from 1.80 to 2.00 per cent silicon and 3.00 to 3.20 per cent total carbon, adding 1 per cent nickel, in the ladle, for machinability. Usually we can dispense with risers and use common gating practice.

70. It is our belief, in connection with this soft iron mixture, that the condition of the carbon in the charge affects the condition of the carbon in the finished casting. That is, a finely divided graphite in the pig iron and the scrap used makes for a finely divided graphitic carbon in the casting, provided the cupola is operated so as to bring the charges down hot and fast. The new style pig now being cast, which weighs only 40 lb., shows a much finer grain structure, and a slightly higher combined carbon than the old pig of twice the size, because the small pigs cool much more rapidly. The use of some outside scrap, of such a size and

wall section that the graphitic carbon will be finally divided and in not too high an amount, is good practice.

CONCLUSION

71. In conclusion, it is our thought that for castings to withstand internal pressures, the most important element in cast iron is carbon. Our practice indicates that decreasing the total carbon content below the percentages usually encountered in high test irons, the means by which we decrease it, and the hot-pouring of these lower carbon irons make for a finer grained structure. This

DATA ON LIQUIDUS SURFACE OF Fe-Si-C SYSTEM

Silicon Per Cent	Total Carbon Per Cent	Temperature at Which Freezing Starts, Degrees Fahr.	Temperature At End of Freezing, Degrees Fahr.	Per Cent Solid Metal When Eutectic Temperature Is Reached	Per Cent of Liquid Eutectic
1.50	2.50	2400	2060	60	40
1.80	3.00	2280	2060	35	65
2.50	3.25	2195	2060	15	85
2.50	3.50	2125	2060	....	100

refining of the grain size provides both pressure-tightness and increased strength.

72. An attempt was made to ascertain the manner in which the iron mixtures mentioned in this article, freeze. Data were taken from the works of Hanson, Honda, Murakami, Conterman, Kriz and Poboril in connection with the liquidus surface of the iron-silicon-carbon system. The accompanying table gives these data. The answer to the question of why a casting weighing 2000 lb., consisting of sections varying from 11/16 to 2½ in. thickness and cast with no feeding heads does not show any signs of internal defects is not apparent to the author of the table. It does show why low carbon irons trap gases given off by the mold and core.

ACKNOWLEDGMENT

73. The author takes this opportunity to express his thanks to Professor G. B. Upton, Cornell university, Ithaca, N. Y., for his aid.

DISCUSSION

Presiding . . . H. BORNSTEIN, Director of Laboratories, Deere & Co., Moline, Ill.

CHAIRMAN BORNSTEIN: This paper by Mr. Judson, and the material in it has received a good deal of attention, both in this country and abroad. It is an interesting paper on low carbon irons and was presented last year as the A.F.A. exchange paper to the Institute of British Foundrymen.

JOHN GRENNAN¹: Recently we ran a test using an electric furnace to determine the difference in strength due to the change in temperature, using a 1.2 in. standard test bar. Instead of finding that the drop in strength was in proportion to the temperature, at high temperatures a small drop had no effect; and then we reached what appeared to be a critical temperature, below which there was a marked drop in strength. This temperature was below 2500° F. The 2380° iron was low in strength, whereas the 2500° iron had the same strength as the 2800° iron. Now, does this come out the same way when using the test bars from the castings? The following table gives the results of our test:

AVERAGE FOR TWO BARS

Pouring Temperature Degrees F.	Transverse Strength Lb.	Deflection In.	Tensile Strength Lbs. per Sq. In.	Brinell Hardness
2,720	2,430	0.28	37,100	198
2,620	2,365	0.267	37,100	193
2,500	2,550	0.250	37,700	191
2,380	2,240	0.246	29,200	187

ANALYSIS

	Per Cent		Per Cent
Carbon	3.09	Ni	0.08
Si	1.98	Cr	0.07
Mn	0.67		

MR. JUDSON: We do not use test bars of any kind on low-carbon cast irons. When we started to cast low-carbon irons, we used the only bar available at that time. It was the standard round arbitration bar, 1-1/4 in. diameter. We felt that such a bar did not lend itself to casting in an iron running 2.50 per cent total carbon and 1.50 per cent silicon. Our practice has always been to test pressure castings, of new design, by blowing one up under actual pressure test. Then we dissect the casting, taking sections from all parts of it. Tensile specimens are turned from these sections and tensile tests made on them. We have never kept a record of our pouring temperatures, so we have no data to indicate what effect a change in temperature has upon the strength.

We have had but little experience with test bars. We do use the 1-1/4 in. round bar occasionally because even with this particular type of

¹ Foundry Instructor, University of Michigan, Ann Arbor, Mich.

low-carbon iron it should be gray throughout. If there is any tendency towards white iron in it, we know that our cupola practice has been off.

Probably if the present program of using test bars of different diameters for the various grades of iron had been in use at that time, we would have followed it.

MEMBER: Mr. Judson, from your experimental work, have you gained any information as to the formation of dendritic structures in low total carbon iron? Have you investigated structures any?

MR. JUDSON: Eight or nine years ago we noticed this dendritic grouping of the graphite in photomicrographs of unetched specimens of 2.50 per cent carbon iron. In those days nothing was said about a dendritic structure so we never paid any attention to this particular type of graphite formation. We did not find a reduction in strength. We have never had a failure in the field with the particular type of cylinder in which we noticed this structure, so evidently it did not reduce the strength of the iron. Incidentally, the photomicrographs were taken from samples cut from the walls of these cylinders and not from test bars or cast-on coupons.

We have also noticed distinct whorl and rosette formations in the graphite distribution. We have not noticed any variations in the strength of the iron in which these formations occurred.

MEMBER: We are producing irons around 2.80 to 2.90 per cent total carbon and sections that will vary anywhere from 3/8 in. up to 2-1/2 or 3 in. in the same casting, and occasionally we will find that we will get a definite dendritic structure. I do not know just what is the cause of it. I do not think it is indicative of good wear. Of course, these castings of ours are machine tool castings and the primary requisite is wear resistance.

CHAIRMAN BORNSTEIN: Perhaps Mr. MacPherran could answer that question.

R. S. MACPHERRAN²: We make about the same kind of iron and quite often we get dendrites. We can relieve the condition a little by the addition of small amounts of chromium. I say in the paper I am to present* this afternoon that we put in small amounts of chromium and some ferro-silicon in the ladle. Both of those will help the condition somewhat. But there are very apt to be dendrites present in any high cast iron. Of course, if the stress runs along the lines of the dendrites, it might be bad, but if we make the stress run crosswise, the dendrites will hardly affect the strength.

I wish to ask Mr. Judson a question or two. First, we weld high test cast iron very nicely; it runs very, very well. Then about his test for shear. That should be a very interesting test but it is not very much talked about or not very much exploited here. I would be very glad to hear what he has to say about shear tests. Also, what do your actual tests show when you make them? If you make test bars, at what strength do they break?

MR. JUDSON: In replying to Mr. MacPherran, I wish to say that our

² Chief Chemist, Allis Chalmers Mfg. Co., Milwaukee, Wis.

*Cupola High Test Cast Iron, A.F.A. Preprint 37-19.

attempts to weld low carbon cast iron have never met with much success. The main reason why we discontinued the practice was that the structure of the metal in the weld was not the same as the structure in the base metal. Another reason was the fact that cracks occurred near the weld. If we had preheated the entire casting before welding, these cracks might not have occurred.

We do not use test bars for the shear test specimens either. On these cylinders we cast the drain boss solid instead of coring it. We then mill a specimen from this boss, the full thickness of the wall. The specimen is then turned down to 0.222 in. diameter, the same as Fremont used in his shear test. Four tests, in single shear, are made from each specimen.

We have accumulated, over a period of years, the results of the shear tests from cylinders which, for various reasons, were defective in the machine shop, but which were completely machined and were then tested to destruction on a pressure test. We have thus accumulated sufficient data to plot a curve of bursting pressures against shear strength. It is our practice to take a shear specimen from each cylinder and test it in single shear. We are then able to predict the actual bursting pressure within 400 or 500 lb.

We have never used alloys of any kind in our low-carbon cylinder irons, nor have we ever made any ferro-silicon addition to the ladle. The cupola charges are made up of steel rails, 20 per cent spiegel and 15 per cent silicon pig.

MR. MACPHERRAN: How is the shear strength determined?

MR. JUDSON: By a single shear test in a machine similar to the Fremont machine. Ours is similar to the Fremont machine as far as the actual shearing action is concerned. We made our own shear block. It was made similar to the one described by G. K. Elliott in his paper published in vol. 34 of the A.F.A. Transactions.

DR. J. T. MACKENZIE²: I am sorry that Mr. Judson used the short quotation from the paper by Johnson and myself because that paper was only speaking of one thing, namely—the height of tuyeres—although I think that the statement in our paper was true, that practically all of the carburization in the cupola takes place between the beginning of melting and the time the iron passes out of the melting zone, which means a little bit below the tuyere.

As far as the fundamental principles of carburization are concerned, there can be only three things, that is, the degree of saturation of the material, the temperature of the melting zone or the coke that it passes through, and the time of contact of the metal with the carbon. The gas phase will probably be a reflection of some of the complex sequences there, which means that a high ash coke will not present as much carbon as a low ash coke, etc. I am sure there is no disagreement on the principles of that. I would, however, dislike very much to see the conclusions from a little piece of work on the height of tuyere used to make it look like we were wrong on some of our assumptions as to carburization.

I wish to question Mr. Judson's illustration on the thermal gradients

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in hot and cold-poured castings. I thoroughly agree with him that hot pouring is the best way to get the castings, but I absolutely disagree with him on his reasons as to why. He has shown here, I believe, some results on some quenching tests in which the outer surface of the casting is kept in a continuously renewed, comparatively cold medium. This is no indication whatever of what happens in the sand mold. If any of you ever have spilled a mold that was about to freeze, I am sure you would have seen that there could not possibly be, in any thickness of casting, a skin with a temperature of 1000° , and an inside temperature of nearly 2600° , as this illustration shows. Convection currents in molten iron tend very strongly to keep the metal at the same temperature throughout until crystallization begins to form, and by that time the sand mold has warmed up so that you have nothing comparable at all to this case of a quenched piece of steel. The curve as shown in Fig. 6 might be somewhere near right, but I cannot believe that anything like that shown in Fig. 7 would happen until the total temperature of the mass has fallen almost to the freezing temperature, and at that time the sand mold is heated up. So I think you have very much less thermal gradients in a hot poured casting than you will have in a cold poured.

MR. JUDSON: My remarks to which Dr. MacKenzie refers, are not to be taken as meaning that I disagree with him and Mr. Johnson. The point that I tried to make was that there are so many factors which determine the carbon content of a cupola melted low-carbon iron that the simple statement as made dismisses the subject too easily. I do agree with him on the principles involved. Our experiences of the past eleven years have been so varied that I did feel that this was an appropriate time to discuss the subject. We have set down a rather rigid set of rules for the cupola men to use when we are melting low carbon iron. In spite of this, we have found that the carbon content varied too widely. These variations were brought about by changes in the cupola operation, which, though they were not noticed at the time, did have a profound effect upon the resulting total carbon. We refer to the paper, as read, for these variations.

Dr. MacKenzie remarked about the illustration on the thermal gradients in hot and cold-poured castings. It is unfortunate that I used numbers representing the temperature which could be construed as actual temperatures. As stated in the paper, the illustrations are schematic only. Actual times and temperatures are not given. It would also have been better if the curves had shown only that section which includes the freezing range. Fig. 8 illustrates the point that I wanted to make, better than do Figs. 6 and 7.

Ferrite—Its Occurrence and Control in Gray Cast Iron

BY R. H. BANCROFT,* NEWCASTLE, IND., AND A. H. DIERKER,**
COLUMBUS, O.

Abstract

Ferrite is normally considered as associated with (a) a slow rate of cooling, (b) a high silicon content, (c) a high carbon content, or (d) some combination of these. The authors in their studies of certain very light sectioned castings found ferrite areas in castings whose carbon content was somewhat below normal. Raising the carbon, the ferrite disappeared. This paper outlines the authors' attempt to find an answer to the question whether a ferrite condition is a function of the carbon content or is the carbon content only one of the many factors involved. A conclusion reached was that any given iron has a definite range of cooling rates within which a normal pearlitic structure will be found. Higher or lower cooling rates will tend to form different types of ferrite designated by the authors as primary ferrite and secondary ferrite.

1. For the purpose of a general discussion we can consider the essential constituents in the microstructure of gray cast iron to be cementite, ferrite, pearlite, and graphite. Ferrite, as an individual phase, is normally considered as associated with, (1) a slow rate of cooling from the melt, (2) a high silicon content, (3) a high carbon content, or (4) some combination of these. The formation of ferrite in the manner indicated can perhaps best be illustrated by means of a few micrographs.

2. In Fig 1, we note that an iron which produces a normal pearlitic structure in a $\frac{1}{2}$ in. section casting will show large ferrite areas when the cooling rate is drastically reduced by pouring in a 4 in. section casting. With the cooling rate constant, ferrite also can be produced by increasing the silicon content. This is illustrated in Fig. 2, which shows the microstructure at the center of two similar castings (rectangular bars 1 in. x 2 in. x 12

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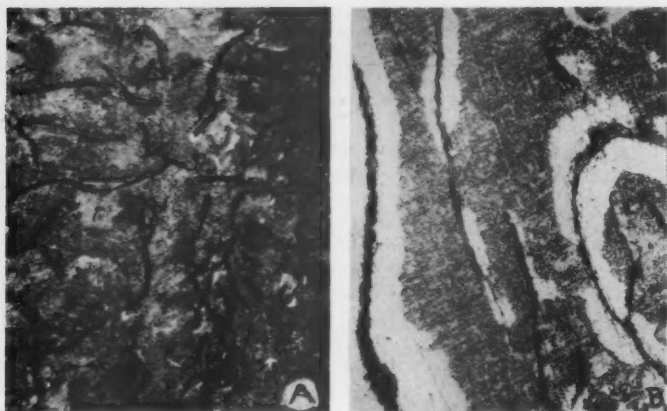


FIG. 1—EFFECT OF METAL SECTION (COOLING RATE) ON MICROSTRUCTURE OF GRAY CAST IRON.

A—CENTER OF $\frac{1}{2} \times 2$ -IN. SECTION 250x

B—CENTER OF 4×4 -IN. SECTION 250x

ANALYSIS OF METAL TC., 3.56 PER CENT; SI., 1.78 PER CENT; MN., 0.50 PER CENT; P., 0.16 PER CENT; S., 0.04 PER CENT.

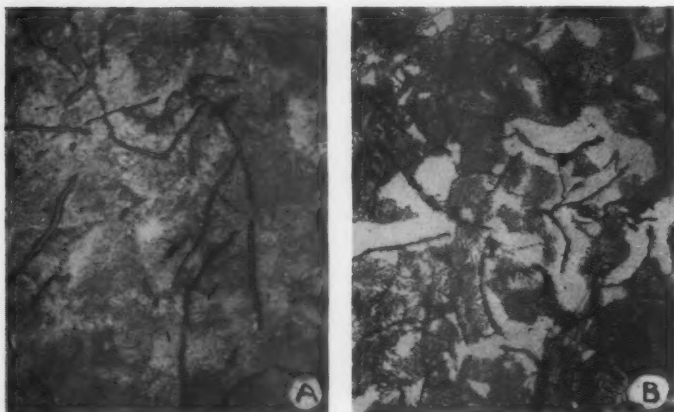


FIG. 2—EFFECT OF SILICON ON MICROSTRUCTURE AT CENTER OF $1 \times 2 \times 12$ -IN. BAR. 250x.

ANALYSIS OF MELTS:

	TC.	SI.	MN.	P.	S.
	%	%	%	%	%
A	3.23	1.60	0.56	0.03	0.04
B	3.26	2.96	0.58	0.11	0.04

in.) poured from two melts whose composition varies, for practical purposes, only in silicon content. A similar effect will be secured if the cooling rate and silicon content are kept constant but the carbon content is increased.

3. The modern skilled foundryman is familiar with the formation of ferrite under the conditions noted and regularly produces castings free from the types of ferrite illustrated. There is, however, a third type of ferrite, occurring under entirely different conditions than those already discussed. This type of ferrite, although of quite common occurrence, is usually ignored or at least

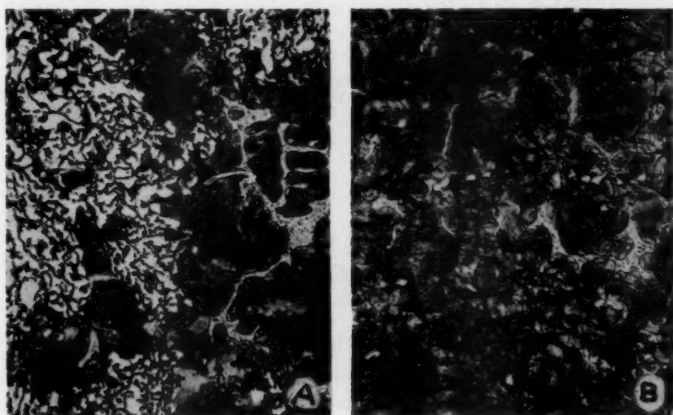


FIG. 3—MICROSTRUCTURE OF NORMAL PISTON RING AND ABNORMAL RING SHOWING CONSIDERABLE FERRITE. 500x.
A—ABNORMAL STRUCTURE.
B—NORMAL STRUCTURE.

unrecognized. It is this type of ferrite that will be discussed in this paper.

IS FERRITE CONDITION A FUNCTION OF CARBON CONTENT?

4. Sometime ago, one of the authors noticed that certain very light section castings, whose normal structure is shown in Fig. 3B, would frequently show considerable amounts of free ferrite as shown in Fig. 3A. Investigation over a considerable period of time revealed that, contrary to what would be expected, the ferrite areas were found in castings whose carbon content was somewhat below normal. When the carbon was raised, the ferrite disappeared. A question then naturally arose: "Is the ferrite

condition a function of the carbon content or is the carbon content only one of many factors involved?" Our attempts to find the answer to this question revealed some very interesting angles to the problem.

TEST PROCEDURE

5. If the conditions described were due to low carbon or to certain minor elements, then pure alloys with high carbon should be free from this particular type of ferrite. Accordingly a series of high carbon alloys were prepared with manganese 0.078 per cent, sulfur 0.014 per cent, and phosphorous 0.015 per cent. The carbon and silicon contents were those listed in Table 1.

Alloy No.	Total Carbon Per Cent	Silicon Per Cent
1	4.37	0.27
2	4.58	0.47
3	4.58	0.67
4	4.40	0.87
5	4.34	1.02
6	4.32	1.26
7	4.22	1.40
8	4.19	1.71

6. From each alloy a test block was poured. The general dimensions and manner of casting this block are shown in Fig. 4. The graduated rate of cooling secured in this block permitted us to study the effect of the rate of cooling on the microstructure of each of the alloys.

TEST RESULTS

7. This study revealed no appreciable amount of free ferrite in alloys 1 to 7, although there were some small isolated areas in blocks 5, 6, and 7. However, in block 8, free ferrite was quite abundant and occurred in two distinct areas one corresponding to a relatively fast and the other to a quite slow rate of cooling. This is shown quite clearly in the micrographs of Fig. 5. Close to the chill was found the typical chilled structure of cast iron. Immediately following the chilled area, large areas of free ferrite occurred, the ferrite in this case being associated with very finely divided graphite. At a still greater distance from the chilled end, the slower rate of cooling produced a normal pearlitic structure and in the heavy section of the block, where the cooling rate was

correspondingly slow, we again find free ferrite. Here, however, it is associated with coarse graphite.

PRIMARY AND SECONDARY FERRITE

8. To prevent confusion, in the remainder of this discussion we will call the ferrite associated with rapid cooling and fine graphite, *primary ferrite*, while the ferrite associated with slow cooling and coarse graphite will be referred to as *secondary ferrite*.

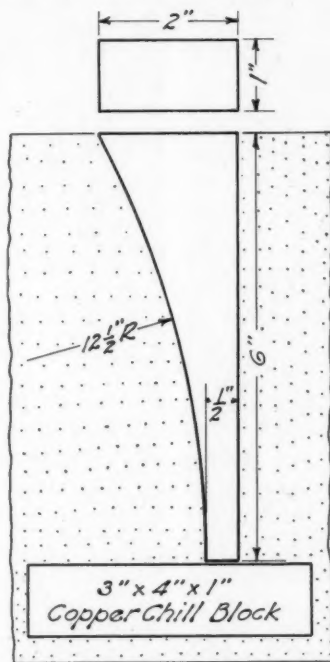


FIG. 4—EXPERIMENTAL CHILLED TEST BLOCK SHOWING GENERAL METHOD OF MAKING SAME.

9. That the phenomena we have just described is characteristic of commercial iron as well as iron from experimental melts, is well illustrated in Fig. 6. These micrographs show the structure in a chill test block from a large automotive foundry. This chill block was of the usual type used in automotive foundries for cupola control and was selected as representative of the iron poured in regular production.

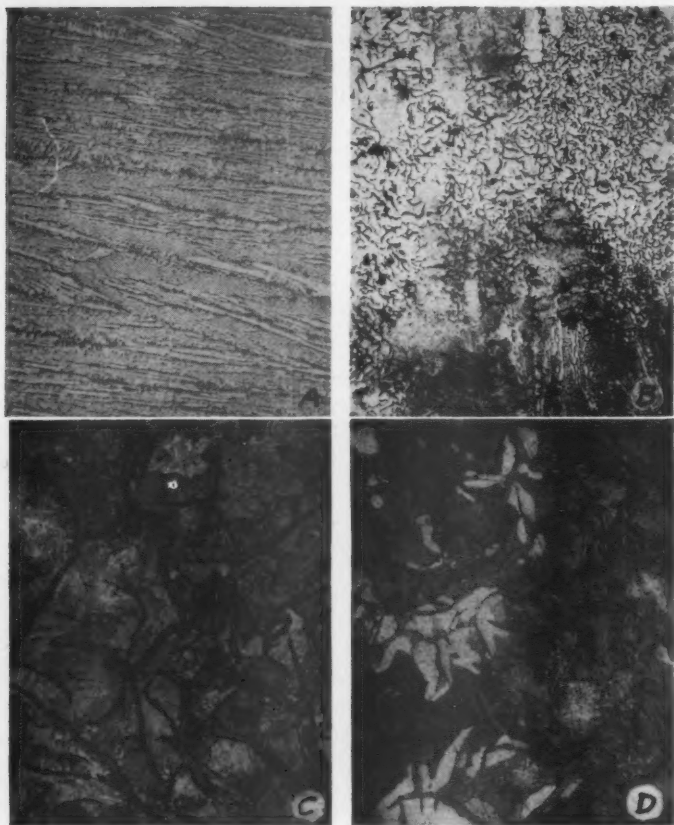


FIG. 5—MICROSTRUCTURE OF TEST BLOCK No. 8 AT VARIOUS DISTANCES FROM CHILLED END. 250x.

A— $\frac{1}{8}$ -IN. FROM CHILL
C— $1\frac{1}{2}$ -IN. FROM CHILL

B— $\frac{5}{8}$ -IN. FROM CHILL
D— $3\frac{3}{4}$ -IN. FROM CHILL

10. It is apparent at this point that, for a given iron, a true pearlitic structure will be produced only when the cooling rate is within a restricted range. At a faster as well as slower cooling rate, free ferrite will appear in the microstructure. The foundryman has little control over section size and hence cooling rates. He must, therefore, depend largely on composition for control of microstructure.

11. As stated early in this paper, secondary ferrite is well

known and its control readily accomplished. What then, can be done about the primary ferrite?

12. In the case of the thin section castings referred to earlier in this paper, it will be recalled that primary ferrite occurred when the carbon dropped below normal. In the experimental work with the variable section test blocks, it will be remembered that primary ferrite only appeared when the silicon was raised sufficiently high. We might logically conclude here that the usual practice of drop-

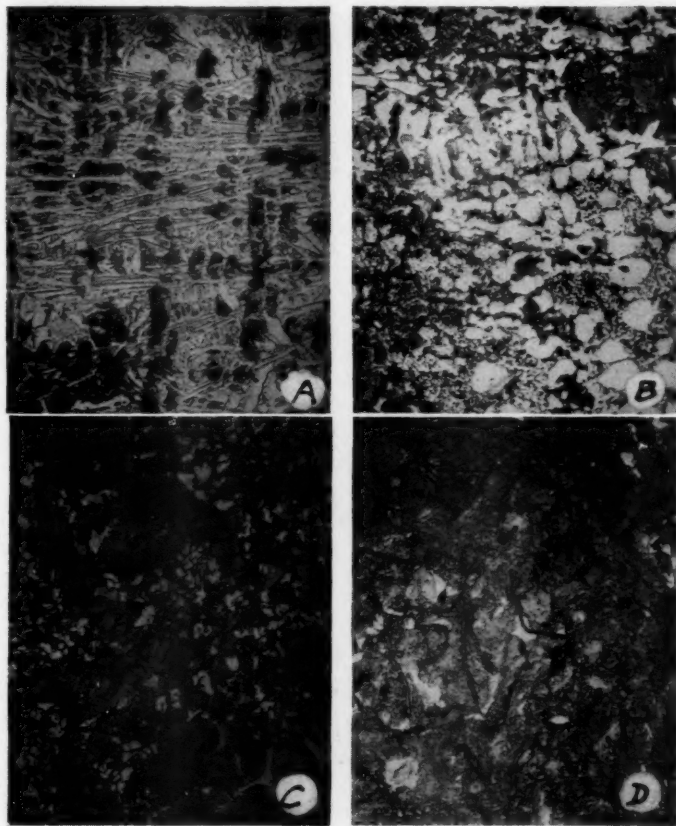


FIG. 6—MICROSTRUCTURE OF COMMERCIAL AUTOMOTIVE IRON AT VARIOUS DISTANCES FROM CHILLED END. 250x.

A—1/16-IN. FROM CHILL.

B—3/16-IN. FROM CHILL.

C—5/16-IN. FROM CHILL.

D—1 IN. FROM CHILL.

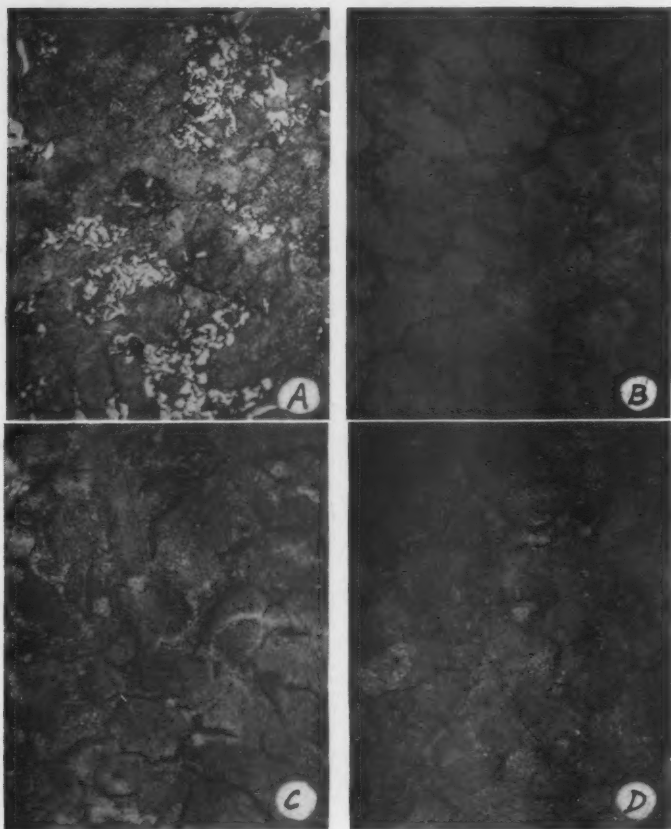


FIG. 7—MICROSTRUCTURE AT CENTER OF $\frac{1}{4}$ x 2-IN. SECTION CASTINGS AND $\frac{1}{2}$ x 2-IN. SECTION CASTING FROM TWO MELTS OF DIFFERENT COMPOSITION. 250X.

A— $\frac{1}{4}$ x 2-IN. SECTION MELT 26.

B— $\frac{1}{4}$ x 2-IN. SECTION MELT 29.

C— $\frac{1}{2}$ x 2-IN. SECTION MELT 26.

D— $\frac{1}{2}$ x 2-IN SECTION MELT 29.

ANALYSIS OF MELTS:

	TC.	Si.	Mn.	P.	S.
	%	%	%	%	%
MELT 26	3.00	1.36	0.48	0.02	0.04
MELT 29	2.56	1.97	0.64	0.02	0.07

ping the carbon and raising the silicon to increase physical properties would increase the tendency toward the formation of primary ferrite. That such is not the case, we can readily see from the micrographs in Fig. 7. These photos illustrate the microstructure

at the center of identical castings poured under the same conditions from electric furnace melts.

13. It will be noted in this case that the relatively slower cooling rate in the $\frac{1}{2}$ -in. section casting produced a normal pearlitic structure in both cases. A more rapid cooling rate, illustrated by the $\frac{1}{4}$ -in. section caused the formation of primary ferrite in the casting from melt 26. However, we find that the $\frac{1}{4}$ -in. specimen poured from the lower carbon, higher silicon iron of melt 29 shows a quite normal structure free from primary ferrite.

CONCLUSION

14. We might show additional micrographs of experimental as well as commercial irons that were examined in this investigation. They all, however, apparently point toward the conclusion touched on earlier in this discussion, *i.e.*, any given iron has a definite range of cooling rates within which a normal pearlitic structure will be formed. Cooling rates higher than this range tend to form primary ferrite or free cementite; slower cooling rates will tend to form secondary ferrite.

15. Unfortunately, there seems to be no simple relationship between primary ferrite and the amount of any individual element in the composition of the iron. The authors have, of course, considered the possibilities of alloys in preventing the formation of primary ferrite. However, investigation revealed irons, alloyed with the usual elements used for that purpose, showed the same susceptibility to the formation of primary ferrite as the unalloyed irons, unless so much alloy was added as to seriously affect the other properties of the iron, particularly machinability.

16. The important question to the user of gray cast iron is "What, if any, effect does the presence of this primary ferrite have on the performance of the iron in service?" An adequate answer to this question can, of course, be obtained only by extended observations of castings under a variety of service conditions. By calling attention to the problem, we trust the necessary observations will be made to enable definite conclusions to be drawn.

17. Our own limited observations to date would indicate that the presence of primary ferrite has a pronounced effect on wear under lubricated conditions, with a marked tendency to cause scoring. It seems also to effect machinability. Hardness and strength, as determined by the usual methods, seem little effected by the presence or absence of this particular type of ferrite.

ACKNOWLEDGMENT

18. The authors wish to acknowledge the helpful assistance of H. H. Dawson of the Engineering Experiment Station, Ohio State University, in preparing the micrographs used to illustrate this paper.

DISCUSSION

... *Presiding*: H. BORNSTEIN, Vice-President, American Foundrymen's Association and Director of Laboratories, Deere & Co., Moline, Ill.

PAUL S. LANE¹: (Submitted as written discussion) Messrs. Bancroft and Dierker have called attention to a very interesting and important structural feature occurring in gray cast iron under certain critical cooling rates.

It is the writer's impression that in England considerably more study and research has been devoted to the occurrence of this "primary ferrite" structure. Other investigators have referred to this same type of structure as "eutectic", "pseudo-eutectic", "supercooled", "sleety", "snowball", etc. The work of Norbury and Morgan indicates that it may be caused to form due to the presence of certain non-metallic inclusions. They have reported that it may be made to occur at will by passing carbon dioxide gas through molten iron which had been previously treated with 1 to 2 per cent additions of ferro-carbon-titanium. A rather complete discussion of this subject is given by J. G. Pearce in the *Foundry Trade Journal* of March 18th and 25th, 1937. Some few observations made by ourselves have indicated that the primary ferrite structure may be related to the atmosphere existing during melting, and we have also noted a lowering of total carbon when such structures appear.

At any event, it is believed that this form of structure is considerably more prevalent than might at first be supposed. It has been observed in recent cylinder castings and in brake shoes and piston rings. (Fig. 8.) Dry wear tests have shown it to have definitely poor wearing qualities, being considerably more harmful from this angle than is the normal or "secondary type" of ferrite.

In paragraph 16 the authors mention that only by "extended observations in service" will we be able to learn more of the effects of this form of graphite. In this connection we recently had occasion to make some automotive brake shoe castings having a section of $1\frac{1}{2}$ in. x $5/16$ in. These particular castings had been produced by two other foundries, but gave rather short life due to rapid "heat checking" or cracks. Examination of these castings showed considerable amounts of this ferrite-graphite eutectic. These had an analysis of silicon 2.30-2.50 per cent, carbon 3.35-3.45 per cent and a Brinell of 190-200.

Plain iron shoes were produced having a strictly eutectoid structure and these gave considerably improved service life before lowering of hardness and strength occurred. More recently these same castings have been

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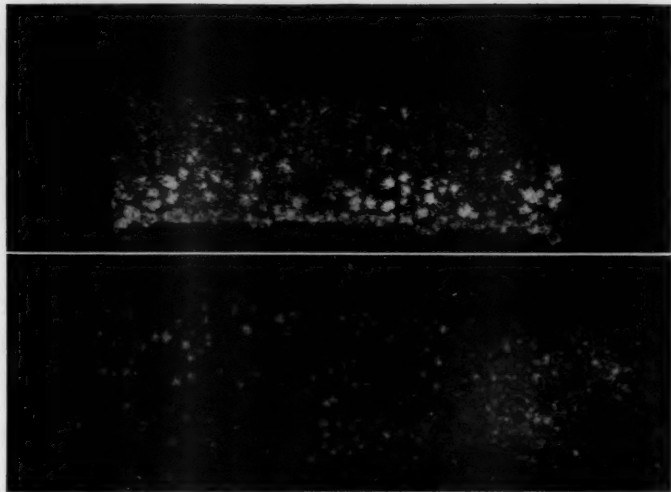


FIG. 8 (*Upper*) SECTION OF AUTOMOTIVE ENGINE BORE, CONTAINING "FERRITE-GRAPHITE EUTECTIC SPOTS." NOTE THAT THESE APPEAR TOWARD OUTSIDE OF CASTING. BRINELL, 200. ETCHED, $\times 5$.

(*Lower*) SECTION OF GRAY CAST IRON BRAKE SHOE EXHIBITING THIS SAME TYPE OF STRUCTURE AS SHOWN IN THE UPPER VIEW. THIS SHOE FAILED TO GIVE SATISFACTORY SERVICE. BRINELL, 200. ETCHED, $\times 7$.

made of alloy cast iron containing nickel and molybdenum, with still further improved performance and service life.

Thus it would appear that, along with the authors' mention of decreased wear resistance, and its effect on machinability, the "primary ferrite" structure likely has somewhat less heat resistance.

M. F. SURLS² and F. G. SEFING³: In discussing this interesting paper the writers wish to point out certain views which they believe will help to clarify some of authors' findings. Regarding the authors' conclusions as stated in paragraph 14 the writers believe that furnace temperature has a very definite bearing on the formation of primary graphite. Irons heated to 2900° F. or over will show a greater tendency toward the production of primary graphite than similar irons heated to a lower temperature even though the pouring temperature remains the same.⁴

In paragraph 15, regarding the relation between primary ferrite and the chemical analysis, the writers have found that with the carbon content at 3.00 per cent or below superheated cast irons (2900° F. or over) tend to produce primary ferrite in arbitration test bar sections.⁴ The effects of alloying elements on a 3.0 per cent C—2.0 per cent Si iron have been reported by the writers recently and it is shown that the carbide forming

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³ Research Metallurgist, The International Nickel Co., Bayonne, N. J.

⁴ Bulletin No. 65 Michigan Eng. Exp. Sta. East Lansing, Mich.

elements decrease the primary ferrite.⁵ Indeed, it is believed that most alloys which stabilize the carbides will help to minimize the primary ferrite.

It is to be expected that the presence of this primary ferrite will be noticed in service performance. The structure is more or less a segregated one, and all the evils of segregation are to be expected. Several investigators have found ferrite to be very detrimental in wear and gall resistant service.

W. H. SPENCER⁶: This is a subject of great interest to all of us, especially to those who manufacture castings small enough to be subject to a rapid rate of cooling, or who deal with irons of a hypereutectic nature, or with extremely hot melting, as in the production of lower carbon cast iron. In our work in piston rings, I believe, all manufacturers have run into this ferrite occasionally. We tried to arrive at some conclusions as to the cause and remedy for it. In addition to the men who have been mentioned this morning as working on this question, we found several others, including two or three Germans, as far back as Diepschlag in 1929. In this country, J. W. Bolton has done remarkable work in this phenomenon in iron.

Our theory of the cause of this structure was that due to the rapid cooling rate, we had super-cooling, and the presence of anything that would act as a nucleus would tend to produce a very rapid precipitation of fine graphite. These fine graphite particles, being close together, would offer a large surface and a short distance of travel for attracting carbon from the surrounding metal,—in other words, diffusion of the carbon out of the associated metal onto the adjacent graphite with its large surface area, thereby producing the ferrite by removal of the carbon from the surrounding iron by diffusion.

About the only method of attack on this problem we could think of was to try to prevent the introduction of the nuclei. There has been a great amount of discussion on nuclei, as to whether it was graphite or whether it was silica slime. Diepschlag said structure could be regulated by the slag which covered the metal. We made some progress, I believe, by the control of the slag in the cupola. That is a question, however, which is still open. The chemical analysis of the slag alone does not seem to tell the whole story. A petrographic study of the slag or a microscopic examination of it is rather difficult, so we reached sort of an arbitrary composition for our slag, with fixed amounts of flux and fixed blast pressure to regulate the oxide as much as possible, and by carefully selecting and controlling all material, we secured good results.

G. P. PHILLIPS⁷: As a practical aspect of this problem, about a year and one-half ago, one of the men in our implement division called my attention to some small cast gears in which they were having excessive wear. He claimed that he detected ferrite at or very near the surface of the gear teeth. At first thought, that seemed rather absurd to us, but on careful examination of a number of gears that were poured with a straight

⁵ "Typical Structures of Alloy Cast Irons" Metal Progress Data Sheet—August, September and October, 1936.

⁶ Metallurgist, Sealed Power Corporation, Muskegon, Mich.

⁷ Metallurgist, International Harvester Co., Chicago, Ill.

iron, fairly high carbon, fairly high silicon, such as is used in implement work, we found that there were appreciable amounts of free ferrite of a very fine nature, similar to that described as primary ferrite in this paper, very near the surface.

As a practical and economical remedy, we tried the addition of varying amounts of chromium, starting with, as I recall it, about 0.1 per cent and going up to about 0.75 per cent, and we found that at about 0.35 per cent chromium we had practically eliminated the ferrite and at about 0.50 per cent chromium, I think we entirely eliminated it. As a compromise, we recommended the use of about 0.35 per cent chromium. That could be used very satisfactorily in these particular castings because the metal section, as I recall, was about three-quarters or one inch thick,—that is, the hub portion of the small gears.

As Mr. Lane pointed out, in castings that are machined, usually we find that the primary ferrite is present as a very thin layer, and in the machining operation with the usual amount of stock that we remove, we eliminate a good portion or most of the ferrite and, for that reason, we do not normally encounter it in cylinder bores and castings of that nature.

DR. JAS. T. MACKENZIE^a: I would like to take exception to one point in the conclusions, and to support one point. Where the authors mention the fact that there is very little effect on the Brinell, we cast some plates for Professor Schlick of Iowa State University some time ago and they had this abnormal primary ferrite, as the authors call it, on the outer surface. It showed very distinctly in the Brinell, the outside of the plates measuring 121 Brinell and the inside measuring 133. So I think possibly it is this small chilled specimen that these authors have worked on which accounts for the fact they did not detect that effect. We had big flat plates, 18 in. x 18 in. and 1½ in. thick.

However, a friend of mine sent me some castings a few years ago that he said the machine shop was having lots of trouble with, calling them hard. We put them under the microscope and found that they had this ferrite on the outside. The trouble was not the hardness of the inside, but it was the difference in hardness of the outside and the inside, and of course, the tool on passing from the soft ferrite on the outside to the strong pearlite on the inside would chatter. For this reason, they were actually having a lot of trouble machining those castings, although the outside was 130 or 140 Brinell and the inside was only 175 to 180.

We never saw this condition until we started melting really hot. The only irons that we have ever found it in, in ordinary work, were for castings—say, down to one-half inch in section, where the iron is melted very hot. It is almost unknown in irons with phosphorus over 0.40. It usually occurs where you pour fairly hot. A good fine, smooth plumbago facing will help it a lot in making it primary ferrite, although it would not do that every time.

R. H. WATSON^b: Mr. Spencer, would you give the analysis of this slag of which you spoke? Would you care to say how much alumina was in the slag and how much iron oxide?

^a American Cast Iron Pipe Co., Birmingham, Ala.

^b Metallurgist, Hanna Furnace Corp., Ecorse, Detroit, Mich.

Mr. SPENCER: In the slag we run we keep the alumina very low. It is under 5 per cent. And the iron oxide seems to be the most important variable. We have tried to control it very closely but find this difficult. We try to keep it under 1 per cent.

J. S. VANICK¹⁰: Mr. Chairman, I have been very much interested in the discussion that has gone along up to this point. Mr. Dierker's comment that there is considerable to be done in controlling the effect through composition, seems to be a very pertinent one where you cannot control the condition in some other way. The change in cooling rate from the chill into the back gray part is very rapid, and in principle is similar to what steel men used to do when they heated a bar to locate the recrystallization temperature in a steel, by heating one end almost to fusion, keeping the other cold, and quenching the bar. From that test they located by fracture the grain refining zone.

We seem to have a similar condition here except that it affects a primary crystallization range associated with a cooling rate which, as in the case of the steel, can be made more controllable by using alloys. With certain alloys, the cooling rate effect is spread out so that the time element (which, in the case of an individually cast piston ring, certainly must be extremely short from the time it is poured until it is solidified) is spread out so that a considerable element of control can be exercised in adjusting it.

Some ten years ago, speaking of a practical problem similar to Mr. Phillips', we had the case of air-cooled motor cylinder castings which involved rapid wear because of their peculiar construction. The foundry was casting copper fins on the outer walls to establish a radiating surface. They bled approximately 50 per cent of the volume of the metal through the mold to freeze these on, got a very hot casting condition that ended up in a structure similar to these that have been shown, with ferrite and the eutectic graphite. At that time we struggled with the problem in terms of alloys, ultimately ending up with about 2 per cent nickel, I believe, and about 0.30 per cent chromium. The initial combined carbon content in those cylinders was about 0.20. The hardness was down around 130 Brinell and the objective was to bring it up to 180 or 190 Brinell and the combined carbon up to as near 0.60 per cent as could be done without chilling the sections or the junction of copper-fin with cylinder wall.

The base composition of the iron was very similar to that of an ordinary piston ring iron except that the cylinder castings might have had a wall about 5/8 in. thick. I have an illustration (Fig. 9) here that must be ten years old, showing the structures. These cylinders, of course, had to be machined to wear well and it was also important that the metal around the copper fins did not chill.

C. O. BURGESS:¹¹ The authors should be complimented for bringing this phenomenon to the attention of foundrymen. We have found, in agreement with Mr. Phillips, that chromium will eliminate ferrite in conjunction with the eutectic graphite. We have also found that the forma-

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¹¹ Union Carbide & Carbon Co., Niagara Falls, N. Y.

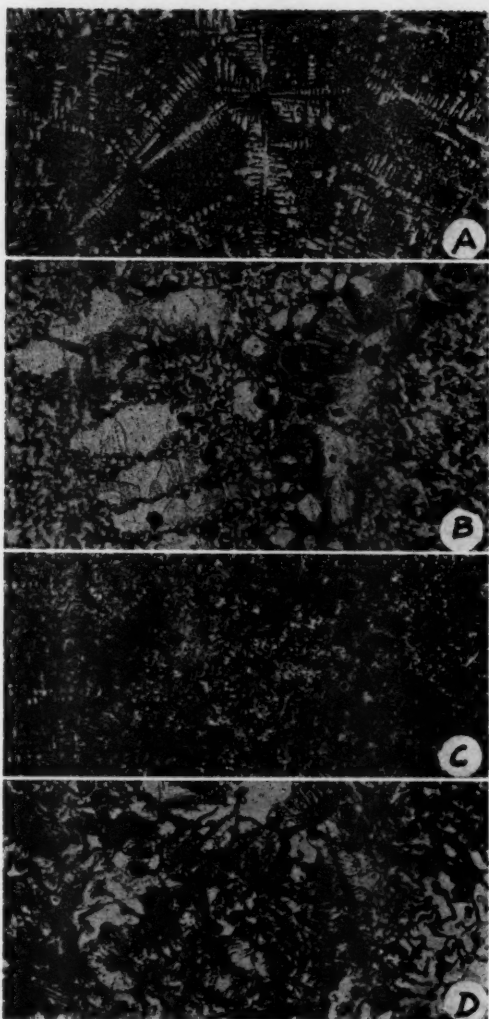


FIG. 9—(A) DENDRITIC STRUCTURE COMPOSED OF FERRITE AND EUTECTIC GRAPHITE IN ENGINE CYLINDER IRON OF APPROXIMATELY 3.50 PER CENT TOTAL CARBON, 2.50 PER CENT SILICON. BRINELL HARDNESS ON CYLINDER OF 135-155 — $\times 100$.
 (B) SAME AS A, $\times 500$.
 (C) SAME IRON AS A ALLOYED WITH APPROXIMATELY 2 PER CENT NI AND 0.30 PER CENT CR. THIS DESTROYED DENDRITIC PATTERN OF A, ELIMINATED FERRITE AND GRAPHITE PATTERN, INCREASED HARDNESS UP TO 180-200 BRINELL ON CYLINDER WALL AND IMPROVED RESISTANCE TO WEAR WITHOUT RISKING OCCURRENCE OF CHILLED ZONES ADJOINING FINS ON CYLINDERS, — $\times 100$.
 (D) SAME AS C, — $\times 500$.

tion of the eutectic graphite can be inhibited by the simultaneous addition of some graphitizer to the ladle. Most success has been attained by bringing down a fairly low silicon iron and adding about 0.75 to 1.00 per cent silicon in the ladle, in which case we get a normal flake graphite rather than one of the fine eutectic type.

DR. LORIG: It seems to me that Dr. MacKenzie and Mr. Sefing brought out one point that is of fundamental importance. It relates to the temperature of the metal as it comes from the furnace. Metal heating temperature has a very profound influence on the precipitation of graphite from the melt and on the formation of primary ferrite. Because of this it would seem that one simple way to control both the graphite distribution and the formation of primary ferrite would be through control of the metal temperature, melting practice and other factors remaining the same. The tendency for primary ferrite and eutectic graphite to form increases with metal temperature and to avoid these formations lower metal temperatures would seem to be in order. In view of the trend in practice toward higher metal temperatures, it would not be surprising that service problems arising from these formations will become much more acute in the future. They may be avoided, of course, if melting practice is altered to suppress these formations. That can be done.

A. J. HERZIG:¹² The only thing that occurs to me in connection with this paper is that we all may have missed the point made by the authors, or at least all of us in the discussion, in that eliminating primary ferrite in one section means we are merely driving the condition into some other section, which may escape our notice. I wonder if we have fully considered that? In other words, if we add alloys, we eliminate primary ferrite near the surface, but perhaps drive it into some other section of the casting. Mr. Dierker intended to bring that out, I believe, in his paper.

R. H. BANCROFT and A. H. DIERKER (submitted as written closure): The authors are quite surprised at the amount of the discussion of their brief paper. Since these discussions range over such a wide variety of subjects and represent such diverse viewpoints we can only reply adequately by taking each one individually in the order in which they were given.

We must take exception to Mr. Lane's impression that considerable study has been devoted to this subject in England. Mr. Lane is evidently confusing graphite with ferrite for the references he cites and the terms he quotes, which incidentally are taken from these references, are concerned only with graphite structures and nowhere in the published reports of English researches does one find reference to the subject covered by our paper. We note that Mr. Lane refers to the primary ferrite structure as a ferrite-graphite eutectic. We wonder on what evidence he bases this assumption. Our impression has always been that the eutectic, when it is found in cast iron, is Ledeburite, a mixture of cementite and austenite. A little study of the evidence we submitted in our paper will indicate that the structure referred to is a secondary one and not a eutectic.

¹² Metallurgical Engineer, Climax Molybdenum Co., Detroit, Mich.

We are glad to learn that Mr. Lane's observations concerning the effect of primary graphite on wear checks with our own.

Messrs. Surls and Sefing's observations concerning the effect of superheating are interesting and, in the main check with our own. However, the effect varies with the conditions of melting and our observations indicate that where the effect is quite pronounced it is associated with a lowering of the total carbon content.

We are quite surprised to learn from Mr. Spencer that so much work had already been done on this subject by others. We are sorry he has not been more specific in his references for we would be interested in reading them. In our investigation, with the excellent and complete library facilities at our disposal, we felt that we had made a complete survey of the published literature. Mr. Bolton makes some reference to this subject in his latest paper. However, this paper was not published until several weeks after ours.

Mr. Spencer's theory regarding the formation of primary ferrite is interesting. We held a quite similar theory but were unable to make it fit the facts. For example the test blocks described in paragraph 5 of our paper were all melted at approximately the same temperature and under the same conditions with slag of the same composition. They were poured at approximately the same temperature and, being identical in shape and size, the cooling rates were the same. Now the only difference in the different blocks was in composition, yet some showed primary ferrite, others did not. It would be strange indeed if nuclei just happened to be in some blocks and not in others.

Mr. Vanick's remarks have been noted. In the case of the Franklin motor cylinder we are at a loss to understand why anyone would want to use a composition similar to piston ring iron in a motor cylinder casting.

We are glad to learn from Mr. Phillips that primary ferrite can, in certain cases, be eliminated in a quite simple manner.

Dr. MacKenzie's remarks are interesting. We freely admit the limitations of our own observations and feel that further contributions such as Dr. MacKenzie has made will lead to the ultimate control of the phenomena.

We note that Mr. Burgess, in his discussion uses the expression eutectic graphite. As in the case of Mr. Spencer's discussion we take exception to this expression and wonder how Mr. Burgess justifies his usage of the word eutectic in this case.

Our remarks concerning Messrs. Sefing and Surl's discussion will also apply to that of Dr. Lorig.

We are appreciative of Mr. Herzig's remarks as we feel they are quite pertinent. Our experience to date would indicate, as has been brought out in the discussion, that the elimination of free ferrite in a particular casting may be quite a simple matter. However, we do not think that there is any one thing that will prevent its forming under every and all conditions. We have found no evidence to support the belief that simply by dropping a small amount of some particular element into a ladle we can set back and say "Now all the castings are going to be free from this objectionable structure."

In our paper we have called attention to type of structure which we call primary ferrite to distinguish it from secondary ferrite. We have shown that this type of structure apparently forms at a higher temperature than would be suspected. We have further shown that the occurrence of this structure is a function of the composition and cooling rate. We are unaware of any previous publication covering these items.

The authors trust that, from the information given, the foundryman, troubled with the type of structure discussed, will be able to find a simple and effective solution to his problem.

Graphitization and Inclusions in Gray Iron

By J. W. BOLTON*, CINCINNATI, O.

Synopsis

The first part of this paper covers some of the questions relative to graphitization in cast iron. In the second the subject of inclusions is reviewed. In any alloy system there exists a tendency for the material to approach the stable state. In cast iron (and in steel) at room temperature the stable state is ferrite and graphite, accompanied by large grain size. To attain the stable state at room temperature requires time. Although their structures may be persistent, commercial cast irons (and steels) are, structurally speaking, unstable alloys. Their physical properties depend largely upon their degree of persistent structural instability. That in turn is affected by composition, cooling rate, method of processing, and other factors. Hypereutectic cast iron may be considered above the eutectoid and below the liquidus as initially a system of primary cementite-*ledeburite*. Primary cementite is highly unstable, free graphite or *kish* being formed below the initial solidification temperature and above the eutectic solidification temperature. That "seeding" in turn accelerates decomposition of the eutectic, *ledeburite*. Ordinarily in the iron carbon series one would expect hypereutectic cast iron to approach the structurally stable state most rapidly, and low carbon steel least rapidly.

The typical graphitic structure of highly hypereutectic cast iron is composed of heavy coarse flakes, formed above the eutectic solidification, surrounded by very fine flakes formed from the eutectic. In less highly hypereutectic metal the graphite arrangement may not be so typical, but great differences in flake size may be found in adjoining locations. The carbon content of the eutectic is appreciably shifted by silicon and by phosphorus. The hypoeutectic cast irons may be considered below the solidus and above the eutectoid as a system initially *ledeburite-austenite*. The carbide usually is more persistent than is the case in the hypereutectic metals. There seems a possibility that the eutectic carbide in hypoeutectic cast iron may have a limited range of stability.

Macrostructure of gray irons is dendritic or cellular, or an admixture of each formation. There is a distinct relationship between the groupings or areas of potentially or actually pre-existent cementite and graphite groupings.

* Chief Chemist and Metallurgist, The Lunkenheimer Co.

NOTE: This paper was presented before the Gray Cast Iron Session of the 41st Annual Convention, Milwaukee, Wis., May 7, 1937.

Typical graphite groupings are in commercial gray iron the pseudo-eutectic, the rosette, and the whorl. An experiment is cited wherein in a given specimen whether or not a given grouping was found depended on the cooling rate. The formations cited above are formed from the eutectic, as distinguished from "kish" graphite. The author suggests that reasons for the high dispersion noted in the pseudo-eutectic formation might be made more clear by considering as an analogy the general laws governing the dispersion of precipitates. The presence of ferritic matrix in pseudo-eutectic graphite areas is explained. Phosphorus (steadite) segregation is useful in revealing macrostructure. Cooling rate is discussed. Slight differences in cooling rate may produce marked changes in structure—i. e., there probably are critical cooling rates for many irons, as well as critical composition ranges.

Theories deduced from study of cooling and heating curves, and certain microscopic evidence are discussed. The author believes that the cementite-austenite eutectic, ledeburite may be actually pre-existent in gray irons, and that the matter of direct graphite precipitation is highly questionable. Experiments on an hypoeutectic cast iron cast into various bars from one half to three inches diameter are described. Photomicrographs of typical structures in each bar size are shown. The author concludes that in the case of this iron the presence of pseudo-eutectic formation or conversely the presence of coarser flake graphite depends upon cooling rate. It is shown that in this case a range of from 24,000 lb. per sq. inch tensile strength to 48,000 lb. per sq. inch tensile strength may be obtained, and the relationship of strength to structure, composition "constant", time varied is indicated.

The author also shows an effect of pouring temperature upon structure and strength. From the evidence above cited and other considerations the author draws the following conclusions. Many of the differences observed in mechanical properties and microstructures of gray irons of similar nominal compositions are traceable to factors influencing the rates and degrees of graphitization reactions. Time available for reaction in a given iron is very important. However, it is apparent that with time and nominal composition constant other factors may be influential. For example the presence of inclusions, or local segregations or the existence of minor constituents might influence the rates hence the degrees. Gray irons may be considered as unstable but ordinarily persistent structures. The time factor in approach to stability may vary tremendously in irons of given nominal composition. It is unnecessary to consider an alloy as freezing in the so-called stable and meta-stable systems respectively to understand what takes place.

Apparent anomalies in behavior of cast irons of given nominal composition often have been noted. There are two "schools" of thought. One utilizes "mechanical" approach, the other believes that effects are essentially chemical. The "inclusion school" believes that supersaturation and surfusion occur because of the absence of nuclei upon which precipitation readily can initiate. Two widely discussed hypotheses are the graphite nuclei hypothesis, and the silicate slime hypothesis. Proponents of the former found on further investigation that the major premise for the hypo-

thesis (existence of graphite nuclei in molten metal) is untenable, if hypereutectic conditions (general, or due to segregation) do not prevail. The silicate—slime hypothesis is most favored by many investigators today. Indirect or circumstantial evidence favors the hypothesis but the slime postulate cannot be proved by direct methods. Manganese sulphide inclusions and the manganese silicon ratio are mentioned. The conversion of inclusions to a fluid condition by the addition of titanium and the bubbling of carbon dioxide is discussed. The author concludes that the question of inclusions remains an open one, and, despite the excellent work already done, much more needs to be found out before we consider ideas now promoted as more than attractive hypotheses.

INTRODUCTION

1. Within the last twenty years our knowledge of the eutectiferous series of the alloys, consisting largely of iron, carbon and silicon, known as cast iron has been greatly augmented. There have been a steadily increasing number of investigations and publications on the subject, and concurrent innovations and improvements in manufacture.

2. Control of the structural forms of iron and carbon is the objective, direct or indirect, of most of those researches. Gray iron has a coherent matrix (iron and various forms of combined or of dissolved carbon) with many graphite flakes dispersed throughout. We strive to control those structural formations by adjustment of composition, choice of raw materials, control of cooling rate, special processing, and similar procedures.

3. This paper discusses the question of graphitization in gray iron, and reviews some of the work done on the subject of inclusions. To obtain proper perspective it has been necessary to stray rather far afield at times, both to sketch background and to utilize analogies.

Knowledge of Composition Inadequate

4. It has been evident for many years that the mechanical properties of gray iron cannot at all times be safely predicted from knowledge of chemical composition, because irons of like nominal composition, presumably cooled from the fluid state at the same rate, sometimes possess widely different mechanical properties. It has been observed that different lots of pig iron with similar analyses gave different results in castings, that the chilling characteristics of charcoal and coke irons may not be the same, that steel addition may have an effect *per se*, and especially that special

processing, such as superheating, often produces very different results than lower temperature melting.

Heredity of Iron

5. The term "inherent properties" has been used, rather inaccurately, to describe unknown factors, and there is said to be a degree of "heredity" due to character, rather than ordinary composition, of raw materials which may be reflected (or "inherited") by the final product. Many hypotheses have been advanced, such as those of J. E. Johnson Jr. on oxygen, of Piwowarsky on graphite nuclei and the like. When Geo. K. Elliott pioneered the commercial electric furnace melting and duplexing of gray irons, he not only introduced a process of great flexibility capable of close control, but also provoked many questions highly disputed to this day, nearly twenty years since his first experiments in 1917.* 1, 2, 3, 4, 5, 6

PART I

STABLE STATES OF CARBON IN IRON

Time Required to Reach Stability

6. Most commercial alloys, and especially cast alloys, are not in a state of structural equilibrium. Such a state implies very slow cooling, so that all structural reactions may have time to become complete. When insufficient time has been allowed for attainment of equilibrium the alloy is termed unstable. Unstability implies that the system is (under condition of temperature, concentration and pressure prevailing) always tending to approach ultimately the stable condition if time be allowed. Cast alloys undergo reactions within a limited time period, and the possible effects of variations in the time factor must at all times be borne in mind. The foundryman is thoroughly familiar with the fact that many irons, which if cooled slowly are of gray fracture, may, if "chilled," exhibit a white iron fracture. Likewise, irons ordinarily casting "white" can, by suitable heat treatment, be made dark in fracture, as in the case of the malleable irons.

Temperature a Variable

7. With a given alloy, hence constant composition, and neglecting pressure, temperature remains as a definite variable. In

* Superior numbers are bibliography references listed at end of paper.

many alloys the solubility of a given component varies with the temperature. For example, a considerable percentage of nickel silicide can be dissolved in molten copper, but a small percentage so added can be detected in the solidified alloy.

8. For purposes of illustration the iron-iron carbide diagram, Fig. 1, will be used for discussion in this section of this paper.

Carbon in Liquid Iron

9. Above the liquidus the molten iron-carbon alloys usually are considered to consist of iron (Fe) and cementite (Fe_3C) the latter possibly slightly dissociated. Direct experimental proofs (as by x-ray methods for example) are difficult because of the limita-

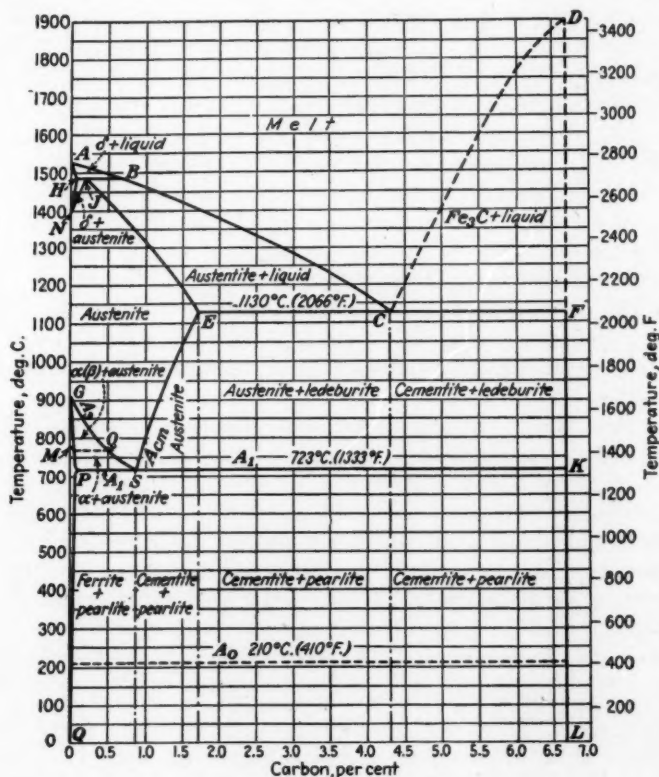


FIG. 1—PROPOSED IRON-IRON CARBIDE DIAGRAM (EPSTEIN, ALLOYS OF IRON AND CARBON, VOL. 1).

tions of technique. Where liquid iron may be considered the solvent (i. e. to the left of the eutectic C, Fig. 1) drastic quenching of eutectiferous alloys usually produces a structure of cementite in austenite. (If a combination of possible atomic carbon with iron to form cementite occurs in a range somewhat below the liquidus and above the eutectic, the velocity of formation must be tremendous!) Thermodynamic evidence also suggests that the solute in liquid metal is cementite.^a

Ferrite and Graphite Condition Below Eutectoid

10. Below the eutectoid (PSK—Fig. 1) the stable condition is alpha iron and graphite; a very small percentage of carbon being dissolved in the alpha iron or ferrite. That this is the case within the percentage of carbon where the eutectic is apparent (ECF Fig. 1,—i. e. 1.7 to 6.7 per cent carbon) has long been recognized experimentally by the ease with which gray irons can be completely graphitized below about 1333° F., the temperature of the eutectoid transformation PSK. White iron for malleabilization and other white irons are graphitized by heating for considerable periods above PSK, leaving approximately the eutectoid percentage of “combined” carbon if chilled from just above PSK. Complete graphitization occurs only when the eutectoid “combined” carbon is precipitated by slow cooling below PSK.

11. It was thought by some that below 1.7 per cent carbon (the steel range) carbide is the stable phase at temperatures below the eutectoid. That viewpoint was somewhat upset by the reported appearance of graphite in carbon tool steel.¹¹

12. More recently a striking confirmation of the theory that iron (ferrite) and free carbon (graphite) are the stable forms has been given by Kinzel and Moore.¹² A steel of 0.15 per cent carbon, 0.49 per cent manganese, 0.02 per cent silicon, 0.023 sulphur and 0.015 per cent phosphorus was employed in a cracking still. It had been in service approximately three years at temperatures somewhat below the eutectoid. Microscopic examination revealed

^a Note—J. B. Austin, whose abstract of the paper¹ by Koerber and Oelsen appears in *Metal & Alloys* (Vol. 4 April 1933 pp. 49-54), considers that paper the most reliable thermodynamic analysis of the iron carbon system. The work of Koerber and Oelsen suggests strongly that the solute in liquid iron carbon alloys is cementite, such cementite possibly being slightly dissociated. Piwowarsky infers² that the reversal of strengthening action at higher superheats may be attributed to dissociation of carbide. The iron-carbon solubility curves of Ruff and Goecke³, and Ruff and Biren⁴ show that above 6.7 per cent carbon the carbon concentration of the melt is necessarily greater than that called for by the formula Fe_3C .

that cementite (from the original pearlite) was absent and nodular graphite had been formed in this low carbon low silicon alloy.

13. Austenite (primary and as a component of the eutectic) is a component above the eutectoid, PSK, and below the liquidus ABCD. For convenience we will disregard the delta iron region and the GPS area in the ensuing discussion.

Austenite is Iron-Carbon Solid Solution

14. By definition austenite is a solid solution of carbon in gamma iron. It is to be noted that the solubility of carbon in alpha iron (ferrite) is very low. The limits of solid solubility are along the lines GSEJN of the diagram of Fig. 1. Within a fully solidified alloy the maximum solubility of carbon is indicated by the line SE.^b

15. Within the nominal boundaries of temperature and of composition there has been, to the writer's knowledge, no evidence of graphitization noted, and the solid solution austenite (carbon and gamma iron) may be regarded as a stable solid phase within the limits implied.

Preliminary Recapitulation

16. Recapitulating, carbon in iron may be considered stable in the following forms:

As largely dissolved carbide above the liquidus.

As a constituent in solid solution in gamma iron, austenite.

As free carbon or graphite below the eutectoid transformation temperature.

Cast Iron, Below Liquidus, Above Eutectoid

17. That leaves the region to the right of the AC_m line, above the eutectoid, and below the liquidus to consider. Let us divide the compositions at the vertical through C, (4.3 per cent carbon in the pure iron-carbon alloys) to the left the hypoeutectic cast irons, to the right hypereutectic. There exist, in the writer's

^b Note—The position of the line SE may be shifted appreciably in carbon concentration by various conditions. The precise condition of carbon in austenite is disputed and not certain. The limiting solubility (SE) is conceived as varying, depending upon whether the austenite is in equilibrium with carbide or with graphite. The latter is discussed by Schwartz and co-workers¹¹ and others. Various additions also are known to affect the limiting solubility.

mind, a number of questions about the hypoeutectic region, into which the commercial gray irons fall. Discussion of that region therefore will be postponed until certain data relative to the mechanism of graphitization are presented.

Hyper-Eutectic Alloys

18. The hypereutectic region is represented by the region above 4.3 per cent carbon to C, and passing along CD. Here, according to the iron-iron carbide diagram, the region CDF is composed of Fe_3C plus liquid, solidifying below the line CF (2066° F.) as hypereutectic cementite and the cementite-austenite eutectic, ledeburite. In iron-carbon and iron-carbon-silicon alloys the hypereutectic cementite is highly unstable under line CD, most readily decomposing with consequent graphite formation. This lack of stability gave earlier investigators much trouble in their studies of this portion of the diagram. In fact it was not until relative persistence was conferred by manganese addition that they were able to carry out certain of their experiments. Even most drastic quenching of the pure alloys did not prevent some graphitization.

19. The actual separation or flotation of free graphitic carbon or "kish" from solidifying hypereutectic irons is a commonly observed phenomena around blast furnaces.

20. Some years ago J. T. MacKenzie furnished the writer a small button of hypereutectic iron for microscopic study.¹⁴ A photo-

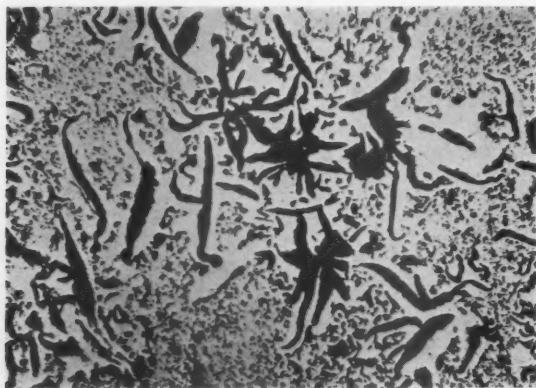


FIG. 2—UNETCHED—X50.

micrograph of this is shown in Fig. 2, the large black flakes probably resulting from decomposition of hypereutectic cementite, the fine flakes between, apparently, largely from decomposition of the ledeburite. The sample had been vacuum fused at 2640° F. and contained 5.2 per cent carbon and 0.04 per cent silicon, the combined carbon being 0.8 per cent. Percentages of manganese, phosphorus and sulphur were lower than those found in ordinary steel analyses. MacKenzie, in a private communication to the writer, estimates that cooling from liquidus to eutectoid took less than two minutes.

21. Schwartz¹⁵ studied a hypereutectic iron, carbon 5.07 per cent, silicon 0.03 per cent, and sulphur 0.014 per cent. Manganese, aluminum, phosphorus and chromium were present in traces only. In its preparation Armco iron was dissolved in HCl, impurities precipitated and removed, and the final oxide of iron reduced by hydrogen and the mass then fused in a graphite block under slight pressure. The resulting ingot was heated 2000 hours at 1200° F. under vacuum, which presumably should remove hydrogen. The original ingot contained both graphitic and combined carbon, and after treatment only graphite and ferrite. After various heat treatment experiments the author concluded that "free"^c cementite decomposed at all temperatures up to the melting point, and its formation ("as distinguished from the crystallization of proeutectoid cementite from super-cooled solutions") was not observed. That is, "free" cementite was unstable in that hypereutectic alloy at all temperatures below the liquidus.^d

22. In discussion of the Schwartz paper¹⁵ Ziegler stated that in a hypereutectic sample which had unexpectedly retained a large spot of cementite, the cementite surprisingly had decomposed into graphite and ferrite after about two weeks at room temperature.

23. MacKenzie and Bolton, Schwartz, and Ziegler had noted that usually about the eutectoid percentage of carbon was found as pearlite on cooling fairly rapidly through the eutectoid transformation range. The observation of Ziegler is most interesting in that

^c Note—We note however, that a hypoeutectic button formed by fusion of the alloy in an arc and immediate quenching, behaved quite differently. After an hour at the 1830° F. there was no graphitization of that sample.

^d Note—We might remark here that the above cited examples from Kinzel and Moore, Schwartz, and MacKenzie and Bolton in themselves partly dispel the idea that production of graphite necessitates the presence of a considerable percentage of silicon. This idea is old, as partial graphitization of irons under 0.10 per cent silicon was noted by Sauveur, Charpy and Grenet, and Foster, all prior to 1912.

the hypereutectic and eutectic cementite plus the eutectoid carbon had completely graphitized at room temperature.

24. We may conclude that in the hypereutectic alloys cementite is unstable below the liquidus and down to room temperature. The degree of instability is high. From what we know about the behavior of hypoeutectic irons, and usual persistence of cementite in those at low percentages of silicon, the "kish" graphite formation of the hypereutectic metals evidently vastly accelerates subsequent graphitization of the cementite of the eutectic ledeburite.

Possible Segregation

25. No one who has worked with irons close to the eutectic composition, hence possibly hypereutectic (due to segregation) in local areas, can fail to note the delicate balance there existing. This is noticeable not only in structural characteristics, but also in mechanical properties. Let the metal get too close to eutectic composition (hence probably exceeding it in spots) and strength values may vary almost 40 per cent with similar melting and pouring conditions and practically the same general compositions.

26. Oftentimes the possibility of a cast iron being hypereutectic is overlooked. Even such careful investigators as Norbury and Rowley¹⁸ state "... it probably is not so generally recognized that graphite can float upwards in partly solidified metal which contain(s) much less carbon than the eutectic composition,

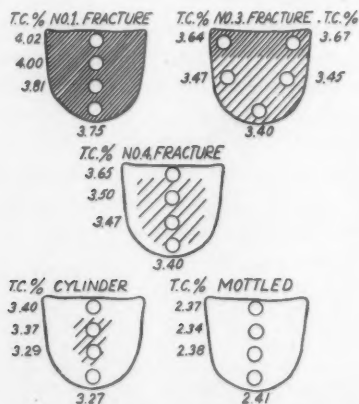


FIG. 3—CARBON VARIATION IN PIG IRON, ACCORDING TO BRITISH CAST IRON RESEARCH ASSOCIATION¹⁸.

... the results seem to support the modern view that graphite is deposited direct from the melt."

27. Bolton¹⁷ calculated the eutectic concentrations for those compositions using the formula

$$E = (4.3 - 0.3 S.) \times (100 - 10 P)$$

and showed that "No. 1" and "No. 2" fractures (Fig. 3) which showed greatest flotation are definitely hypereutectic, "No. 4" is close to eutectic and also shows flotation, and the definitely hypoeutectic material "mottled" shows no flotation. Thus the assumptions and deductions of Norbury and Rowley are deemed untenable because the shifting of the carbon concentration of the eutectic, due to the effects of silicon and of phosphorus, was not taken into account.

Recapitulation

28. All the above may be briefly summarized as follows:

- (1) Carbon probably exists in the melt largely as cementite or iron carbide.
- (2) The solid solution, austenite, within its limits of carbon saturation, is stable above the eutectoid temperature. Above the eutectoid temperature and below the liquidus it is in equilibrium with higher carbon components (proeutectoid cementite, ledeburite, graphite).
- (3) The hypereutectic alloys graphitize very readily below the liquidus.
- (4) The solubility of carbon in ferrite is much lower than its solubility in austenite. Although usually carbide is first formed and the graphitization is relatively slow, the final stable state at room temperature is ferrite-graphite irrespective of the carbon content of the alloy or the presence of a high or of a very low percentage of silicon.
- (5) There are three stable conditions here recognized:
 - (a) Iron plus cementite, liquid.
 - (b) Austenite, solid solution.
 - (c) Ferrite-graphite, two distinct components.

Questions Remain

29. The preceding summary leaves the following pertinent questions relative to the hypoeutectic and approximately eutectic cast irons of commerce:

(1) Is the carbide stable in the liquid phase just above the eutectic and below the liquidus? (i.e., Is graphitization initiated above or at the initial solidification temperature?)

(2) Is cementite first formed (as the eutectic ledeburite) or is graphite formed directly on initial solidification?

(3) Are there conditions where cementite (in the eutectic ledeburite) may be stable somewhat below the initial eutectic solidification

(4) What factors change the time necessary for attainment of the stable states and how do they act?

30. If we could answer these questions, if we clearly understood these matters, we could with greater confidence attempt certain methods of practical control and in all probability be able to make even better and more closely controlled alloys at lower cost. We perhaps could avoid the sometime evil effects of heredity, we could control grain size and the like. Certainly we would know better how to approach the subject of inclusions.

31. Having sketched briefly the general aspects of stability at either side of the hypoeutectic (or commercial cast iron) field, a short review of the mechanism of solidification in the related fields is proposed to be followed by specific study of the hypoeutectic or commercial cast iron field. Conditions that may be found when approaching equilibrium and the relative speeds at which equilibrium may be approached were considered above. Obviously commercial alloys rarely are in a state of equilibrium, and in gray irons the various factors promoting "quality" usually are those that oppose equilibrium and that produce persistent non-equilibrium conditions.

SOLIDIFICATION OF STEELS

Dendritic and Cellular Formations

32. During solidification cast steels often form dendritic patterns. Central axes with branching secondary and tertiary axes are formed in what often is referred to as "fern leaf" or "pine tree" patterns. During that solidification the first formed parts are lower in carbon and impurities, i.e., they approach pure iron in composition, the impurities being progressively greater in the mother liquor. The net result of dendritic crystallization would be that the central austenitic axes would be relatively low in carbon, and the dendritic borders would be richer in carbon and

impurities, if diffusion were inhibited. Diffusion of carbon, however, within the temperature range of formation of these austenitic dendrites is rather rapid, and ordinarily the final dendritic columnar crystal may not vary much in carbon content from its center to its boundary. However, phosphorus is relatively slow to diffuse, and its persistent segregation may be employed to reveal the dendritic outlines. Thus, if we deep etch cast steel we often find a very markedly dendritic pattern. Special reagents and heat tinting are useful in many cases.

33. Dendritic phenomena are responsible for the columnar crystallization often observed in cast ferrous and non-ferrous alloys. (A clear cut example of dendritic formation in a nickel base alloy is shown in Fig. 4.) Columnar formation in cast steel is promoted by hot pouring, heavy sections, poor conductivity of the mold, etc., in short by slow cooling through the ranges between liquidus and solidus. Growth of columnar crystals takes time, and on rapid cooling successively larger amounts of relatively equiaxed grains are found.

34. Dendritism may or may not be persistent. Slow cooling below final solidification promotes granulation and the microscope usually shows a polygonal grain formation. Original dendritism in such cases then is recognized only by revealing segregations,



FIG. 4—X100.

such as those of phosphorus in case of steel as mentioned previously. In hypereutectoid steels, on slow cooling below the liquidus the excess cementite is rejected to the grain boundaries of the granular austenite as envelopes. (These show white on picric acid etch against a dark background, usually pearlite.)

35. In later considering hypoeutectic irons (commercial cast irons) the presence of primary austenite during solidification and its possible persistence and other effects may well be remembered, and possible analogies between the solidification of cast steels and cast iron recalled.

STRUCTURE OF HYPEREUTECTIC IRONS

36. When the marked graphitization tendencies of hypereutectic irons are sufficiently restrained so that a white iron structure results, the typical formation is a fine cellular ground mass of the austenite-cementite eutectic, ledeburite, with long straight flakes of primary cementite. The system, a highly unstable one, is ledeburite-cementite. It readily breaks down, the primary cementite graphitization above the eutectic temperature frequently being observed as kish formation; kish being largely flaky graphite which separates out in the interval liquidus to solidus. Thus hypereutectic irons cooled slowly tend to approach eutectic composition—as is noted in pig iron analyses. A characteristic graphite structure in low silicon, highly hypereutectic iron was shown in Fig. 2, coarse flakes apparently formed from graphitization of



FIG. 5—UNETCHED—X100.

primary cementite, and certainly suggestive in outline of that formation, and also a finely dispersed pseudo-eutectic graphite in the ground mass, probably resulting from, and certainly resembling in structural dispersion, the cementite of the eutectic ledeburite.

37. In less highly hypereutectic metal the structure may not be so strikingly characteristic, but great disparities in flake size may be noted as in Fig. 5. A sample, taken from 1.3 in. dia. test bar¹⁸ made for the A.S.T.M. Impact Investigation contained:

	Per cent
Carbon	3.95
Silicon	1.90
Phosphorus .....	.07
Manganese .....	.65
Sulphur .....	.06
Comb. Carb. ....	.80
C + 0.3 Si.....	4.52

38. The tensile strength of this iron was about 18,300 lb. per sq. in., and the brinell about 131. The whorl flake grouping, characteristic in many nearly eutectic irons, was observed in both coarse and fine graphite areas. The presence of and "seeding" by a small amount of the presumable decomposition product of primary cementite in this alloy apparently accounts for the presence of the large coarse whorls. This and other observations have led the writer to the conclusion that a hypereutectic condition, either due to general composition or to local segregation is likely to produce great differences in flake sizes in various area of some specimens.

39. Nipper¹⁹ advanced the idea that it is possible for carbon segregation to take place in cast irons, particularly when super-cooled. For example in a slightly hypoeutectic iron the primary austenite (dendritic) formation may be so rapid that the liquid remaining may be slightly hypereutectic rather than eutectic in composition.

COMMENT ON SILICON AND PHOSPHORUS

40. In alloys of iron and carbon the eutectic occurs at about 4.3 per cent carbon. In commercial practice we are dealing with alloys of iron, carbon, silicon, manganese, phosphorus, sulphur, etc. These additional elements certainly distinguish the commer-

cial alloys from the binary iron-carbon alloys and alter their behavior in many ways. Silicon undoubtedly promotes graphitization, but, as previously shown, the presence of considerable percentages of silicon is not essential to the ultimate attainment of the stable state, ferrite and graphite. Silicon then may be viewed as an accelerant of graphitization even in steels.*

Calculations of Eutectic Concentrations

41. Without considering the possible accelerative mechanism, attention is directed to the displacement of the eutectic carbon by silicon. Each per cent silicon displaces the carbon content of the eutectic about 0.3 per cent to the left, possibly as much as 0.33 per cent.^{21, 22, 23, 24, 25, 26} Thus the position or carbon content of the eutectic can be approximated by the formula

$$E_c = 4.3 - 0.3 \times \text{per cent silicon}$$

where E_c = calculated eutectic carbon.

(Sometimes the formula $E_c = 4.3 - \frac{\text{Per cent Silicon}}{3}$ is used, corresponding to $0.33 \times$ per cent silicon.)

42. Conversely the relative position of an iron-carbon-silicon alloy on the diagram (Fig. 1) can be approximated by the formula

$$C_e = \text{per cent carbon plus } 0.3 \times \text{per cent silicon}$$

where C_e can be called effective carbon content, to give an idea of the proximity of the ternary alloy to the eutectic concentration.

43. This indicates that although the total carbon content of a given cast iron may be less than 4.3 per cent the shifting of the eutectic by silicon may cause such an alloy to be hypereutectic—for example:

	Per Cent
Total Carbon	3.6
Silicon	2.5
C_e	4.35 (hypereutectic)
E_c	3.55 (thus 3.6 per cent is hypereutectic)

When this measuring stick is applied it is seen that many of our commercial irons are close to eutectic composition. The writer is suspicious of any irons where C_e is over 4.0 per cent because of the possibility of other factors further shifting the position of the eutectic to the left, and the possibilities of segregation.

44. That the action of silicon in promoting the change from white iron (ungraphitized) to gray iron (graphitized) is under

* Note—This was noted long ago by Charpy and Cornu-Thenard.²⁰

some conditions very abrupt was shown by Hatfield.²⁷ Increase in silicon content also raises the temperature of eutectic solidification and of the eutectoid transformation, and lowers the percentage of carbon in the eutectoid pearlite. Its effects on graphitization are more marked in the higher carbon irons. These remarks on effects of silicon are introduced as suggestive of some of the possible influences on graphitization and are in no case intended to serve as analyses of the direct mechanism of the actions of that element.

Phosphorus Shifts Eutectic Concentration

45. Phosphorus also is known to lower the carbon content required for the eutectic.²⁸ The exact amount of lowering for a given amount of phosphorus probably is not very accurately known. It apparently is not constant, and seems more marked at lower percentages of phosphorus. Some earlier metallurgists estimated that since steadite (the phosphorus rich component) contains about 10 per cent phosphorus and 90 per cent iron, and since its density is close to that of cast iron, the relative position of the alloy in the iron carbon alloy could be estimated by dividing the effective carbon content C_e by the factor $(1.00 - 0.1 P)$ where P = phosphorus percentage, or conversely the shifting of the eutectic could be calculated by multiplying the calculated eutectic E_e by $(1.00 - 0.1 P)$. Application of the method gives a result fairly consistent with experimental work of Wüst, and has been employed by a number of metallurgists, including the writer. It, however, cannot be considered scientific, as at the temperature of solidification of the eutectic, as is well known, the iron-phosphorus-carbon rich portion is yet fluid.[†]

46. Phosphorus also is known to lower the temperatures of initial and of eutectic solidification, but apparently has little effect upon the temperature of eutectoid transformation. Being, in cast iron, a constituent of the last component (loosely referred to herein as steadite) to solidify it frequently is found in grain boundary positions as loose female dendritic networks, rather easily distinguished on microscopic examination.

[†] Note—Bolton²⁹ has shown that "steadite", apparently solidifying as a ternary component, readily diffuses its carbon as carbide (and not as graphite as implied by Kekulé) and ultimately forms, in gray iron, a binary formation. That component is persistent, although not truly stable.

47. The above comments on the effects of phosphorus are not intended as a review of the subject, or as an explanation of the complete mechanism of its action within that interesting range from the liquidus to the steadite transformation at about 1800° F. However, the influence of phosphorus and of silicon on the eutectic concentration and temperature, and the visible distribution of the phosphorus rich component are typical among many influences that must be borne in mind when interpreting experimental data. Effects of manganese, sulphur, "alloys" and other constituents and components also should be studied.

HYPOEUTECTIC IRONS

Cementite Often Persistent

48. In many hypoeutectic irons the cementite phase is relatively persistent. If at the initial eutectic solidification direct graphitization occurs, this may imply that eutectic solidification of the alloy and dissociation of cementite (of the liquid) are simultaneous. This possibility will be discussed more fully later. At present we will approach the subject on the assumption that deposition of cementite as such precedes graphitization. The mere fact that on very rapid cooling cementite is formed readily might be attributed to surfusion. The fact that cementite, in the eutectic ledeburite, is arranged in a definite crystalline pattern implies time is necessary for orientation of the constituents of the solidifying metal. There even is some question as to whether or not cementite in the eutectic ledeburite, (with austenite the other phase) may not be partially stable just under the initial eutectic temperature. (Note—When primary cementite is present, the system is unstable.)

49. The experiment of Northcutt³⁰ for example showed that an iron 3.4 per cent carbon and 1.4 per cent silicon (originally gray) when melted and poured just above its melting point in a thin stream into cold water showed a definite partly eutectic pattern and graphite was absent. The writer heated a perfectly gray iron sample, (carbon 3.19 per cent, silicon 2.74 per cent, phosphorus 0.41 per cent, a section of the bar about $\frac{3}{4}$ in. long and $\frac{1}{2}$ in. dia.) as cast for one hour at 2000° F. and oil quenched. The formerly highly graphitic sample, polished and unetched is shown in Fig. 6. The graphite has been mostly reabsorbed. The etched sample Fig. 7 shows the formation of cementite and the suggestive eutectiform

arrangement. The higher magnification photomicrographs Figs. 8 and 9, especially Fig. 8, are quite suggestive.*

50. This particular case suggests, in this instance, that in the solid state the graphite (stable phase at room temperature in the alloy as shown by annealing experiments) was reabsorbed apparently just under the eutectic temperature, and cementite formed. If so the latter must be considered stable here.

51. Too many of the researches designed to ascertain whether graphitization starts at the eutectic solidification (on cooling from

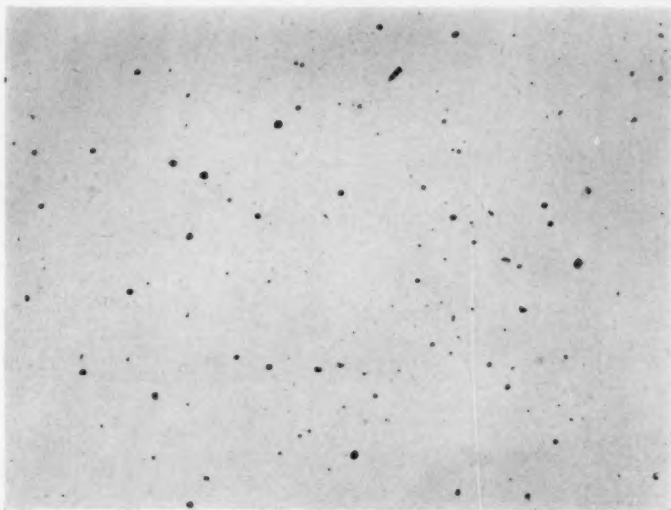


FIG. 6—UNETCHED—X100.

* Note the laminated effect and the apparent shrinkage cavities, the latter especially about the "point" on the formation on Fig. 8, also the cracks in the same structure. Very unfortunately a graphite determination was not made, and the writer suspects that some of the black particles shown in Fig. 6 may not indicate graphite. A calibrated thermocouple was placed against the specimen. The specimen was heated on a silica plate and dumped from there into a wire basket already immersed in Houghton No. 2 quenching oil. The sample had not changed appreciably in shape as would be expected were the eutectic temperature appreciably exceeded. Cooling curves on this type iron showed an eutectic arrest at 2065° F. Assumption that there might have been a difference in temperature between couple and specimen (hence some liquefaction) may not materially change the argument. This type of experiment deserves repetition under rigidly and precisely controlled conditions—for example, couple welded against specimen, and special atmosphere employed.

liquid) introduce the factor of appreciable time, which possible error will be referred to later in this paper. The experiments of Northcutt and of Bolton have been cited as typical among several like revelations in the literature.

GRAPHITE GROUPINGS IN EUTECTIC AND HYPOEUTECTIC IRONS

Macrostructure, Dendritic or Cellular

52. The macrostructure of gray iron may be largely dendritic, largely cellular, or an admixture of both types of forma-

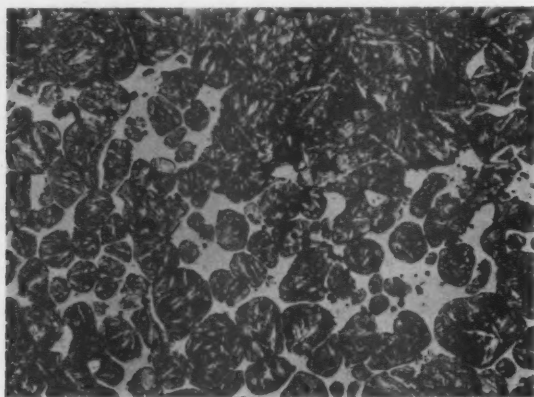


FIG. 7—ETCHED—X100.

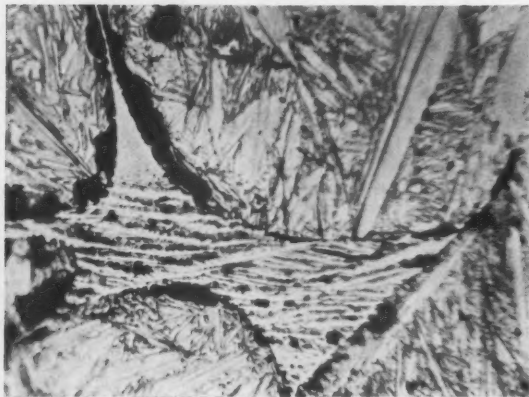


FIG. 8—ETCHED—X1000.

tion.^{31, 32, 33} Dendritic formation is more likely the more hypoeutectic the material, and ordinarily dendritism is noticed more often when cooling has been fairly rapid. When cooling has been relatively slow, diffusion acting within the range below the liquidus and above the eutectic makes it likely that the primary austenite will be more nearly uniformly saturated with carbon, rather than possessing a low carbon central core structure. The dendrites are likely to be larger, hence often unnoticed on regular microscopic

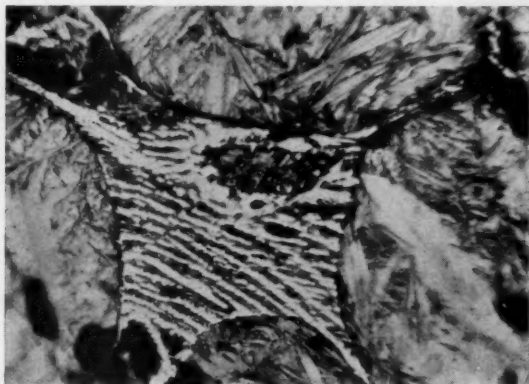


FIG. 9—ETCHED—X1000.

examination. On slow cooling below the eutectic there apparently may be a tendency toward granulation.

53. Dendritism often can be noted by merely looking at a specimen polished for microscopic study, as stated years ago.^{31, 32} Sometimes it is revealed distinctly by the outlining graphite pattern, as in the photomicrograph Fig. 10. Sometimes it is not so clearly apparent. That, in gray iron, graphitization always borders the initial dendritic outlines does not necessarily follow. The writer has noted this lack of relationship when examining annealed gray irons with sodium pierate etching, but photomicrographs were too indistinct for reproduction. It can be seen in some austenitic irons by ferric chloride etching, as in Fig. 11. Boyles³⁴ has successfully applied the methods of heat tinting. This investigator, working with small samples quenched from various temperatures above the liquidus, between liquidus and eutectic, and

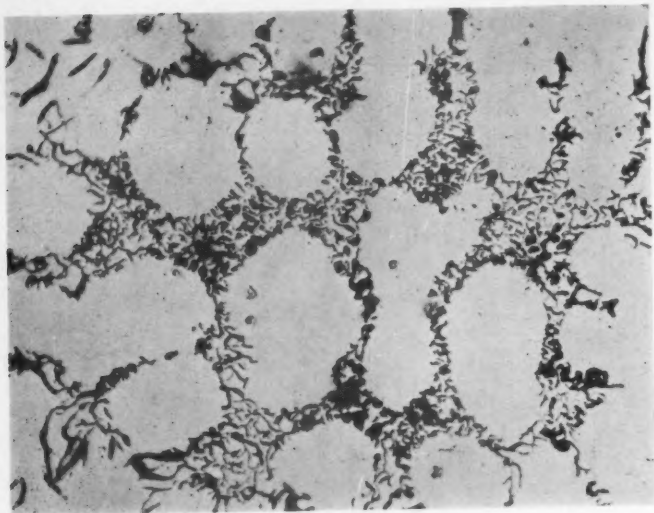


FIG. 10—UNETCHED—X500.



FIG. 11—ETCHED, FERRIC CHLORIDE—X100.

below the eutectic was able to show very clearly the development of the primary austenite (between the liquidus and the eutectic).

Graphite and Cementite Groups Seem Related

54. It has been shown³⁵ that the graphite flake formations or groupings bear a distinct relationship to the forms of potentially (or possibly actually) pre-existent cementite. Ordinarily initial graphite precipitation in a mottled iron is at a cementite-austenite interface. In hypoeutectic and eutectic cast irons when free cementite is formed, the eutectic ledeburite contains most of it. During graphitization, particularly during the early stages, such cementite is the initial source of the graphitic carbon. As noted^{32, 33} compositions approaching the eutectic show very distinct evidence of granular cellular structure, visible in macrostructure, microstructure, fracture and often on machined surfaces.

55. This similarity of arrangements has been noted by other investigators. A recent publication³⁶ concludes that the microstructure of even a malleable casting is in large measure determined by the microstructure of the white hard iron.

Classes Formations as Pseudo-Eutectic, Rosette and Whorl

56. The most typical structural arrangements of graphite in commercial gray irons are the rosette and whorl, and under certain conditions, the pseudo-eutectic grouping. All these are di-

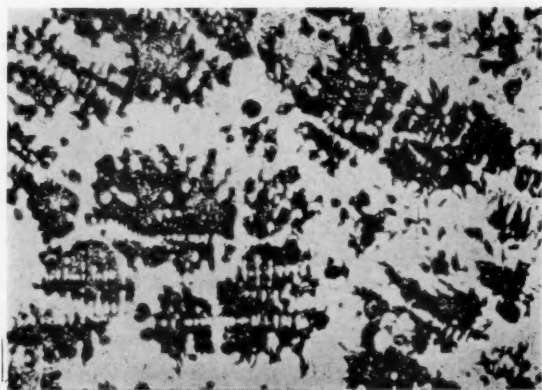


FIG. 12—UNETCHED—X75.

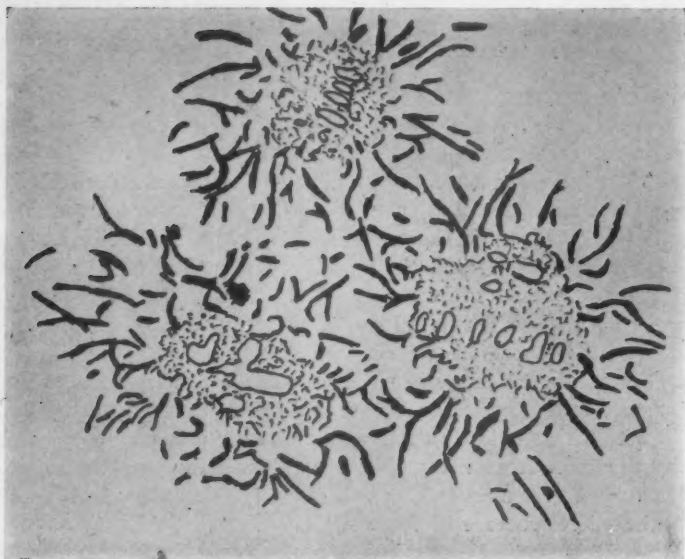


FIG. 14—REPRODUCTION AT 100 DIAMETERS.

rectly inter-related, and directly related to potentially pre-existent ledeburite formation. Fig. 12 represents groupings of (black) pseudo-eutectic formations. A small sample had been poured into a sand mold, and withdrawn and quenched as soon as it had solidified enough to handle. Figs. 13, 14, 15 and 16 are reproductions of graphite groupings^h from a 1.2 in. test bar of slightly hypoeutectic composition, Fig. 13 near the edge, Fig. 16 at the center of the bar.

^h *Note*—Although to the experienced observer the groupings may be fairly well apparent on inspection of a photomicrograph, selection of single formations can be made more clear by the method here employed. A tracing of a single grouping is made from the film or plate, using pencil and paper, printing white on black and black on white. The extremely fine structures of course can only be suggested, but flakes one thirty-second inch and longer can be traced with surprising fidelity. Such reproduction is much to be preferred to diagrams, and (insofar as we are aware) has not been used previously to illustrate graphite flake groupings. Fig. 17 shows how easily one may become confused by looking at a coarse structure, where the grouping may not be very apparent unless an attempt is made to isolate it.



FIG. 13—REPRODUCTION AT 100 DIAMETERS.



FIG. 15—REPRODUCTION AT 100 DIAMETERS.

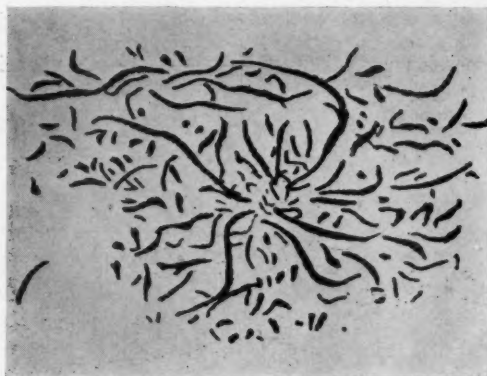


FIG. 16—REPRODUCTION AT 100 DIAMETERS.

Effect of Cooling Rate on Formations

57. Fig. 13 is a typical single grouping near the outside of the bar, a rosette formation, the interior largely pseudo-eutectic, with flakes around the exterior. Fig. 14 shows three groupings, somewhat further from the outside.¹

¹Note—Three are shown to illustrate the method of selection. Obviously in between the cell or granule outlines there is a region wherein some judgment must be used as to just what cell some of the individual flakes should be assigned to, as there is evidence of overlap. That is significant.

58. A slightly diminished amount of the *pseudo-eutectic* formation and larger exterior flakes are noted. In Fig. 15 nearer the center of the bar the amount of pseudo-eutectic is rather small, the flake structure much more evident. In Fig. 16, the center of the bar, the pseudo-eutectic formation is gone, and the rosette formation typical in the preceding illustrations has been superseded by a whorl. The overall size of the cell is greater than those shown in the preceding illustrations.

59. Recapitulating:

(a) The fine pseudo-eutectic formation, markedly suggestive of potentially pre-existent ledeburite formation, is found when cooling is rather rapid or when other causes retard graphitization.

Dispersion

60. A comparison of the dispersion of a precipitate occurring in the solid state with the dispersion of precipitates from liquids as understood by chemists may be interesting. P. P. von Weimarn has expressed this latter as follows:

$$\text{Dispersion coefficient} = \frac{\text{concentration}}{\text{solubility}} \times \text{viscosity}$$

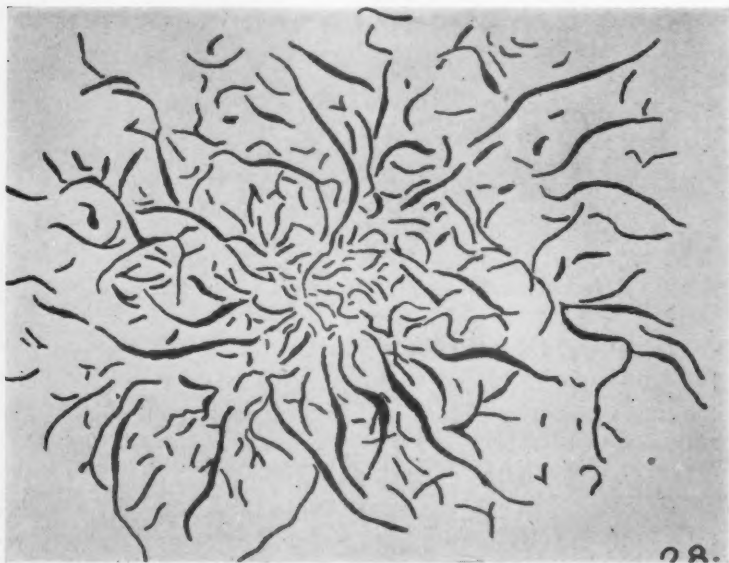


FIG. 17—REPRODUCTION AT 100 DIAMETERS.

If then we consider concentration constant, solubility is lower as temperature decreases and viscosity increases as temperature decreases. If cooling be practically instantaneous, or if relative persistence is great, graphitization itself may not occur although the ledeburite structure will be very fine on relatively rapid cooling. With suitable composition, there is surfusion, and (analogous with the precipitate from solution law above) dispersion is high when limit of supersaturation is exceeded.

61. (b) The *rosette* formation contains a pseudo-eutectic core, surrounded by flakes.¹

62. A conceivable mechanism is that precipitation first occurs in the outer area of the eutectic cell possibly because of segregation, possibly because of the phenomena of graphitization in mottled irons first commencing at the eutectic-austenite inter-faces. The precipitation of the pseudo-eutectic core then might take place as temperature decreases slightly.

63. Another is that the pseudo-eutectic precipitate occurs first, then flake growth ensues. A possible difficulty with that explanation is that it implies that flake growth occurs at a temperature lower than the pseudo-eutectic precipitation.

64. (c) A common conception of the *whorl* formation is that the center of the eutectic granule is the nucleus at which graphitization is initiated and from which flakes radiate. Conversely precipitation may be conceived as starting at the periphery and converging toward the center, because the finer flake structure is concentrated near the "nucleus." If that be the case, it may infer actual cementitic precipitation prior to graphitization.

65. Attention has been directed to the formation of pseudo-eutectic graphite, and, in the more eutectiferous irons, to the relationship of that formation to the rosette and the whorl formations. The writer has stated¹⁴ that from a three dimensional viewpoint structures such as the whorl are roughly spherical. Let us examine the relationship of the matrix structure to graphitization.

Note on Matrix Structure

66. Fig. 18 is from the same bar about the same location as Fig. 13. Note the ferrite within the pseudo-eutectic graphite areas, and the coarser flakes in the pearlitic areas. Another photomicro-

¹ Note—Often small austenitic dendrite residues are found in the ground mass.

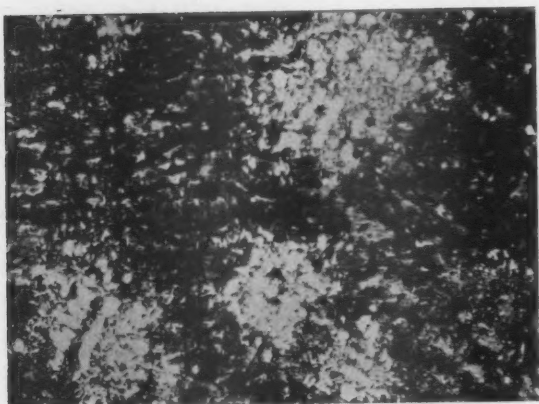


FIG. 18—ETCHED—X100.

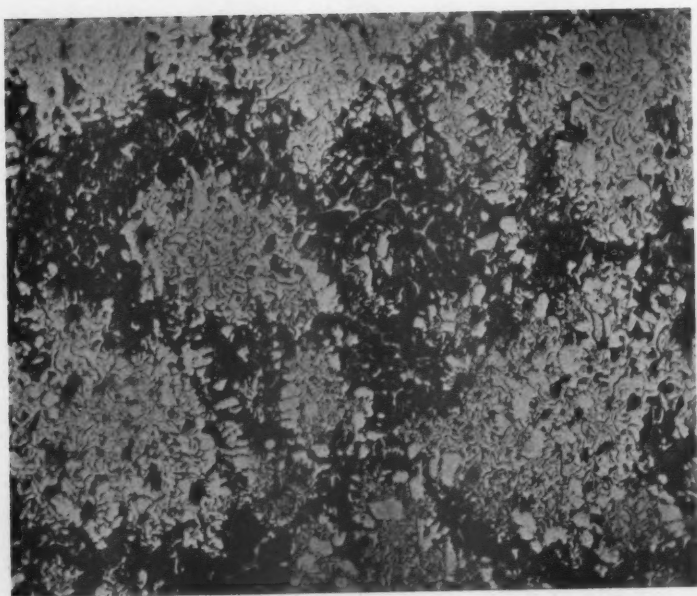


FIG. 19—ETCHED—X100.

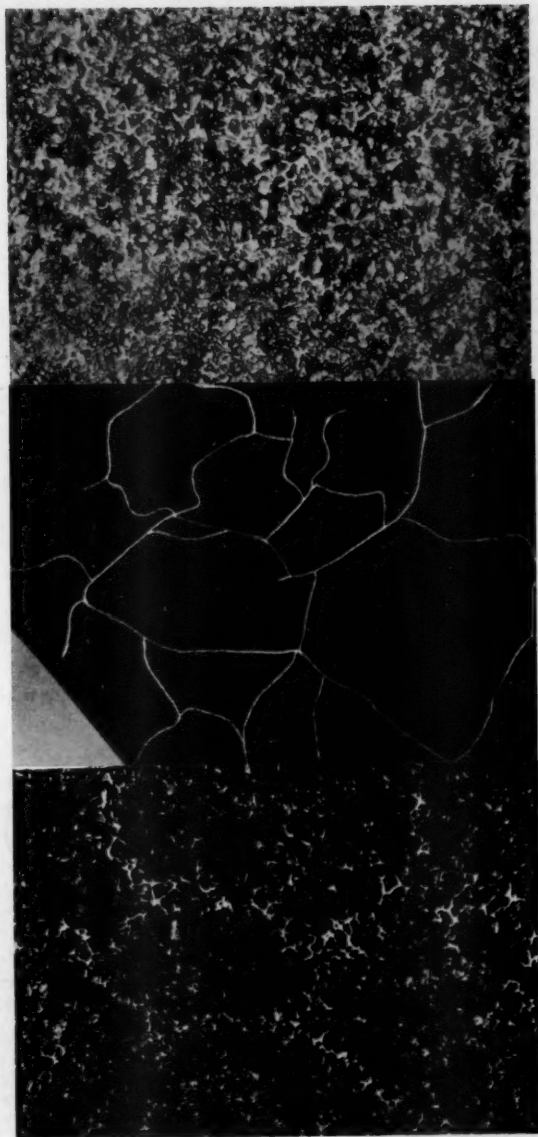


FIG. 20—(LEFT) ETCHED X100.

FIG. 21—(CENTER) TRACING AT 100
DIAMETERS OF GRAIN BOUNDARIES OF
FIGS. 21 AND 22.

FIG. 22—(RIGHT) ETCHED—X100—
SAME SECTION AS FIG. 20.

graph (Fig. 19) from another sample shows a large amount of ferrite, and little room left for flake formation. The general granular or cell-like distribution of ferrite-graphite groupings and the particles of steadite in the pearlite areas between those groupings are evident.*

67. Fig. 20 is a photomicrograph of a largely pearlitic matrix slightly hypoeutectic iron. The 0.4 per cent phosphorus segregated as "steadite" can be seen as a broken white network. Fig. 21 is a tracing whose lines follow the steadite network. (Note—Such tracing is more readily done from a plate or film than from a photomicrograph.) The polygonal network formation is characteristic in most nearly eutectic irons. Fig. 22 is a photomicrograph of exactly the same area as Fig. 20, so handled and photographed that the more highly graphitic areas show darker. Note that the areas along the steadite network are lower in graphite.

68. When hypoeutectic structures are examined, evidence of primary austenite residues become more common. The effects of cooling time on such structures is important, and we will devote some discussion to that factor before resuming the general discussion of structure.

NOTES ON COOLING RATE

69. It is particularly interesting to consider what the effects of cooling rates are upon a moderately hypoeutectic iron. All are familiar with the structure of a hypoeutectic white iron, with the dendrites of *prima*-austenite, surrounded with the later formed mass largely ledeburite. As is shown in Fig. 23, graphitization in mottled irons commences at the austenite-cementite interfaces. If an iron is cooled rather rapidly, but not rapidly enough to produce "chill" pseudo-eutectic graphite pattern follows the external pat-

* Note—The writer has noted for many years now the usual appearance of some small ferritic areas, (apparently low carbon primary austenite residues) within the pseudo-eutectic formations, when these occur in slightly hypoeutectic irons. These may act as ferrite nuclei. Ordinarily one might find it difficult to conceive a very rapid graphitization immediately below the eutectoid. May we not mention that the large surface area of the small graphite flakes, the short migration paths, and the presence of probably low carbon austenite core formation, which would normally transform largely to ferrite on passing through the eutectoid, make the hypotheses that the ferrite in the pseudo-eutectic is formed below the eutectoid (rather than being a result of local impoverishment of austenite above the eutectoid) a reasonable assumption? Note that where, to the right of the eutectic, primary austenite is at no time a component, that the pseudo-eutectic formation often may be seen in a pearlitic background.

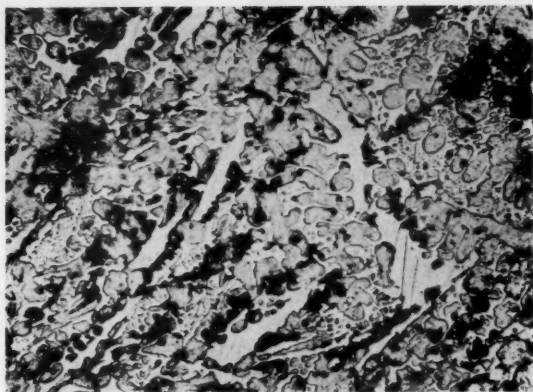


FIG. 23—ETCHED—X75.

tern of the austenite dendrites (Fig. 10). The cementite (probably pre-existent) in the dendritic fillings often graphitizes with great rapidity, a very fine flake structure often being found in a ferritic matrix.¹

70. The degree of graphitization, the general grain size and the fineness of the lamellar eutectoid structure all are directly affected by cooling rate, within the range from about the temperature of eutectic solidification (ECF, Fig. 1) to below the eutectoid transformation (PSK, Fig. 1). As is well known these structural modifications markedly affect physical properties, such as strength and hardness. What perhaps is not so generally recognized is that in many cases segregation may be influenced by cooling rate from liquidus to eutectic solidification.

71. As has been shown by the writer^{37, 38, 39, 40, 41} total time from eutectic solidification to eutectoid transformation varies

linearly as $\frac{\text{Volume}}{\text{Surface area}} \left(\frac{V}{a} \right)$. Cooling rate in an ordinary green sand mold usually is faster than in dry sand for small sections, because of the heat absorbed in volatilizing the moisture, but in sections larger say than the 1.2 in. test bar, castings usually cool somewhat more rapidly in open dry sand molds than in finer green sand molds.

¹Note—This form is referred to by some as "graphite eutectic of the stable system."

72. Various tests,^m published by the writer indicate that a $\frac{1}{2}$ in. dia. test bar may cool at a rate of over 400° F. per minute from the eutectic to the eutectoid. (Range of about 700° F.)

73. A 4 in. dia. bar may require well over three hours to pass through the same temperature range and remain about an hour at the eutectoid temperature, the rate of cooling, eutectic to eutectoid being about 3.5° F. per minute. As might be expected low carbon iron of markedly hypoeutectic type cools more rapidly than more nearly eutectic types.ⁿ

74. The rate of graphitization within the temperature range just below the eutectic and well above the eutectoid must be tremendous when one considers that with suitable composition $\frac{1}{8}$ in. sections can be cast perfectly gray. Certainly it lends grave doubt to many attempts to prove graphitization above or at the eutectic by ordinary quenching methods.

Critical Cooling Rate

75. Everyday experience teaches us that in some irons very slight differences in cooling rate under certain apparently critical conditions cause very marked changes in structure—for example, the narrow line of demarcation in a "picture frame" structure, and the low degree of quasi-isotropy noted in some irons. Cooling rate gradients as well as composition gradients may and often do bring about marked structural (and also mechanical) changes within the same casting, even in so simple a casting as a test bar. Certainly we are justified in being cautious about accepting every new hypothesis that comes along. In spite of all the research that has been done there are many things that we do not know about the simpler alloys, let alone the possible effects of special processing, inclusions, and the like on more complex alloys.

^m Note—In these experiments couples insulated except for the tips were used. Pouring temperatures were kept approximately the same for different irons, specifically in the range 2460° to 2500° F. For each set the iron was all taken from the same large ladle. There is no question but that at such cooling rates lags existed between actual and recorded temperatures. That this should be is apparent to all familiar with thermocouple pyrometry. It probably is partly evident also in the very marked depression of the thermal arrest points noted for small sized bars.

ⁿ Note—Hamasumi¹² ran a number of experiments, pouring into heated molds. His fastest cooling rate was about 510° F. per minute (through range 2065° to 1650° F.) and the slowest (to 1650° F.) was about 160° F. per minute. His sand cast 1.25 in. dia. bar cooled at a rate of about 80° F. per minute.

EXAMINE THEORIES

76. Let us examine, for illustrating the possibilities inherent in the above suggestions, several studies on the question of possibility of direct graphitization at or above the eutectic solidification.

Thermal Analyses

77. Ruer and Goerens⁴³ ran a series of thermal analyses on a relatively pure iron-carbon alloy 2.5 per cent carbon, originally a fully white iron structure. They heated to 2448° F., and cooled at a rate of about 135° F. per minute. One thermal arrest was apparent, at about 2050° F. (That rate of cooling in a commercial gray iron would likewise lower the apparent arrest temperature.) Cooling was continued to 1884° F. The sample was then heated from 1884° to 2131° F. and cooled to about 1870° F., and the procedure repeated a total of ten times.

78. On reheating the first time only one clear cut arrest was found at 2095° F. and on cooling, an arrest at about 2084° F. Ruer and Goerens apparently concluded that the first three points (2050° F., 2095° F., and 2084° F.) represented the formation and separation of the cementite-austenite eutectic, ledeburite. Now by the time, on second reheating, the eutectic temperature range was approached again a total of nearly 17 minutes had elapsed with the iron held within a range of about 1870° F. to about 2095° F. We well know that within a portion of that temperature range at least cementite in the eutectic ledeburite is unstable, and that continuation of the experiment should ultimately produce a gray or graphitic iron.

79. Upon the second reheating two arrests were noted (2095° F. and 2107° F.), but only one on cooling, (at about 2084° F.). After the fourth heating the first (2095° F.) step disappeared and the second (2107° F.) had grown in intensity, and that condition obtained until the end of the experiment. However only single steps occurred on cooling throughout the whole experiment, and those at practically constant temperature, about 2084° F.

80. Reuer and Goerens concluded that the 2095° F. arrest represented the iron-cementite eutectic, 2107° F. the iron graphite

Note—Graphitization must ultimately occur within some portion of that range and the reheating temperature (about 2130° F.) and times were such that it is possible that all graphite was not dissolved on each reheating. In fact the iron could not have been fully molten on any of the reheatings.

eutectic. The implication here must not be lost sight of. It is that an iron-graphite eutectic exists at a temperature above the iron-cementite eutectic, hence that under certain conditions the iron-graphite eutectic is normal, and the iron-cementite eutectic a result of surfusion.

81. In other words graphite can separate directly upon solidification of the alloy. If that be the case our knowledge of the possible effects of inclusions, etc., would be subject to different interpretation, hence, different ultimate controls than would be the case were the deposition of cementite always to occur prior to the precipitation of graphite.

82. It may occur at times, to the casual reader, immaterial just what the mechanisms of graphitization may be, but even a very cursory reconsideration of that viewpoint reveals, that to a considerable degree, our future progress must be based upon accurate diagnoses.

Rate of Solution

83. Years ago Moldenke showed that white iron melts more readily than gray iron, because cementite goes into solution more rapidly than graphite does. Honda⁴⁴ and Kasé⁴⁵ ran experiments similar to those of Ruer and Goerens, and Honda concluded that the two-stepped arrest on heating up is indeed a result of the differences of the velocity of the dissolution of cementite and the graphite respectively. Like Ruer and Goerens, Honda and Kasé observed only a single stepped arrest on cooling. Honda reports that in a hypoeutectic iron quenched from some appreciably lower temperature marked graphitization occurs. That experiment resembles that of the author on a commercial cast iron; see page 18. Results similar to those of Ruer and Goerens and of Kasé have been reported by Piwowsky.⁴⁶

84. There has been (to the writer's knowledge) no case where a clear two-stepped arrest was observed on cooling—i.e. on cooling there is only one precipitation, that of cementite.

85. The work of Von Keil⁴⁷ apparently shows merely that conditions promoting coarse graphite formation also result in raising of the eutectic temperature.

86. In the writer's opinion the thermal data so far published indicate that in the hypoeutectic alloys on cooling the austenite-cementite eutectic probably is formed first, and graphitizes during

and below the eutectic solidification, the double stepped arrests on heating are caused by differences in solubility.*

Solidification Temperature Not Constant

87. As is well known the actual temperature at which the eutectic solidification may occur varies according to the elements aside from carbon and iron present, and apparently is influenced by cooling rate, superheating and other factors.

88. In the hypoeutectic alloys, whether the eutectic ledeburite is partly stable just below initial eutectic solidification is a question. It appears that the influences of various treatments, components, etc. work directly on cementite formation and indirectly on graphitization.

Microstructure Evidence Questioned

89. A number of microscopic studies have been made to ascertain whether graphitization might not occur during solidification, and an iron-graphite eutectic formed. In some of those studies, for example that of Hanemann,⁴⁸ irons so close to eutectic composition were used that the possibility of segregation cannot be lightly dismissed. Hanemann's iron was 4.15 per cent carbon, with an appreciable amount of silicon, and therefore readily could be conceived as having some graphite from locally hypereutectic areas. Surfusion would promote such segregation.

90. His own experience plus study of published data leads the writer to the interpretation of microscopic data as indicating that in hypo-eutectic gray irons cementite in ledeburite may be actually pre-existent, rather than merely potentially so, and that, compared to hypereutectic alloys there may be some limited range of stability of the precipitated cementite. That is, the system austenite-ledeburite acts differently than the system austenite-cementite; the latter as observed in hypereutectic irons where partial graphitization may and often does occur above the eutectic solidification temperature.

* Note—References above cited are chosen as typical of a number published. It is suggested that other investigators working along the lines of Ruer and Goerens and of Honda and Kasé after getting the thermal data hold the small pieces of finally graphitized samples at temperature just below the eutectic solidification, say 2055° F., and, after suitable period of time drastically quench same, to see whether just below the eutectic most of the graphite cannot be reabsorbed, and cementite formed.

HYPOEUTECTIC IRONS IN VARIOUS SECTIONS

Experiment Outlined

91. The following experiment was conducted in order to evaluate the effect of section size and cooling rate on a given iron.

92. Iron at 2810° F. at the cupola spout was admixed with 15 per cent liquid steel and a series of molds poured, after double transfer, all within the range of 2505° to 2545° F. The metal contained 2.27 per cent Si, 0.24 per cent P, 0.052 per cent S, 0.60 per cent Mn, 0.08 per cent Cr, and no nickel. Hardness varied with the "as cast" sizes, but tests showed the annealed bars about the same hardness, 135 Brinell.^p The tensile tests indicate that when cooled from liquid to eutectoid transformation in about 26 minutes this iron probably has reached approximately constant maximum "grain size." The differences in the specific gravities "as cast" and annealed are to be expected. It is noteworthy that the gravity tests tend to confirm the trend of the total carbon analyses. Table 3, page 531, gives the data of this experiment.

Cooling Rate and Microstructure

93. How do these test results compare with studies of microstructure? The photomicrographs of respective sections of "as cast" bars correspond with diameters as follows:

Fig. 24—At edge of ½ in. dia. bar.....100 Dia. unetched

Fig. 25—At edge of ½ in. dia. bar.....100 Dia. etched

Fig. 26—At center of ½ in. dia. bar.....100 Dia. unetched

Figs. 27 and 28—Same as Fig 24, but at 500 dia., highly dendritic section.

Fig. 29*—Same as Fig. 26, but annealed.

Fig. 30—Near edge of 1 in. dia. bar.....100 Dia. unetched

Fig. 31—Center of 1 in. dia. bar.....100 Dia. unetched

Fig. 32—Center of 1.2 in. dia. bar.....100 Dia. etched

Fig. 33—Center of 2.0 in. dia. bar (CI-149).100 Dia. unetched

Fig. 34—Center of 3.0 in. dia. bar (CI-136-

137)100 Dia. unetched

Fig. 35—Center of 3.0 in. dia. bar (CI-148).2000 Dia. etched

(* Pseudo-eutectic graphite areas slightly retouched.)

^p Note—Drop in carbon content in larger sections had been noted before and commented on by several investigators, and as yet is not satisfactorily explained.

Structural Changes Progressive

94. This series of photomicrographs reveals the progressive changes in structure as cooling rate is changed. The analysis indicate a largely pearlitic matrix. Study of the different sections



FIG. 24—UNETCHED—X100.



FIG. 25—ETCHED—X100—SAME SECTION AS FIG. 24.

etched and at higher magnification (Fig. 35) showed coarser pearlite laminations in the larger bars. The conditions were such that the pearlitic phase was largely persistent on casting (although readily broken down on subsequent annealing). The most readily noticeable structural differences, as influenced by time, are the arrangements and what we may loosely call "grain size" of graphite flakes.

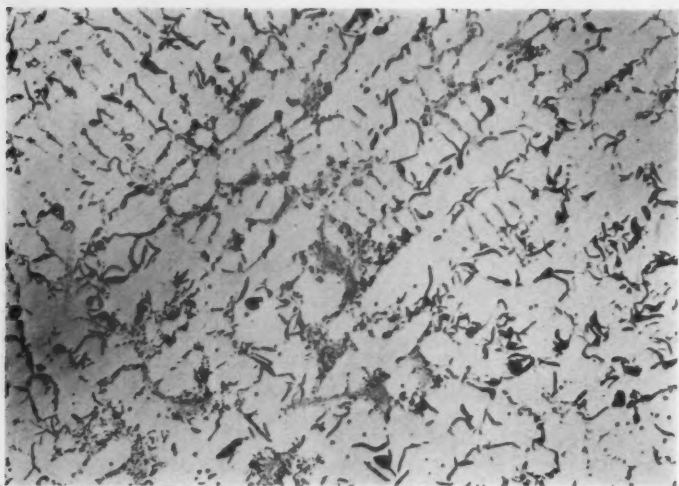


FIG. 26—UNETCHED—X100.

95. At the edge of the $\frac{1}{2}$ in. bar (Fig. 24) the graphite, largely pseudo-eutectic, is in the female dendritic pattern. This also is clear in the etched sample (Fig. 25). Fig. 26, the center of the same bar, shows that part of the pseudo-eutectic graphite has coalesced, although the dendritism yet is quite apparent. Figs. 27 and 28 are higher magnifications pictures of a dendritic area near the area of Fig. 24. (Note:—At 100 dia. the pseudo-eutectic graphite often is so fine that it is not clearly shown in printed reproductions of photomicrographs.) Fig. 29 is from the center of a companion $\frac{1}{2}$ in. bar which was annealed at 1600° F. The arrangement of graphite is essentially the same as in Fig. 24.

96. At a very high rate of cooling (edge of $\frac{1}{2}$ in. bar) graphite is pseudo-eutectic in character and dendritic in arrangement. At a somewhat slower rate (center of $\frac{1}{2}$ in. bar) both

pseudo-eutectic and flake forms are apparent, and the dendritic pattern remains visible, although coarser.

97. At the edge of the 1 in. dia. bar (Fig. 30) some pseudo-eutectic areas are evident, groups being larger than in $\frac{1}{2}$ in. dia. bar. Considerable flake graphite appears. In the center of the 1 in. dia. bar (Fig. 31) only traces of pseudo-eutectic structure remain and only slight suggestion of dendritic residue is seen in the largely flake graphite.

98. The center of the 1.2 in. bar shows no pseudo-eutectic graphite and there was faint suggestion of dendritic outline. The

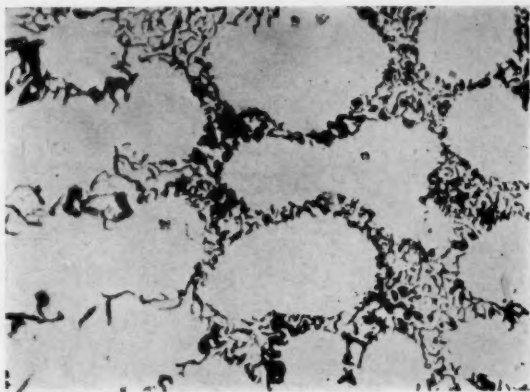


FIG. 27—UNETCHED—X500.



FIG. 28—UNETCHED—X500.

latter is much more clearly seen in Fig. 32, which is from the center of the 1.2 in. bar.

99. Fig. 33 from center of 2 in. (poured on end, and "dirty," also sample poorly polished) shows no pseudo-eutectic graphite. Fig. 34 from 3 in. dia. bar (also cast on end, and "dirty") shows only well separated graphite.

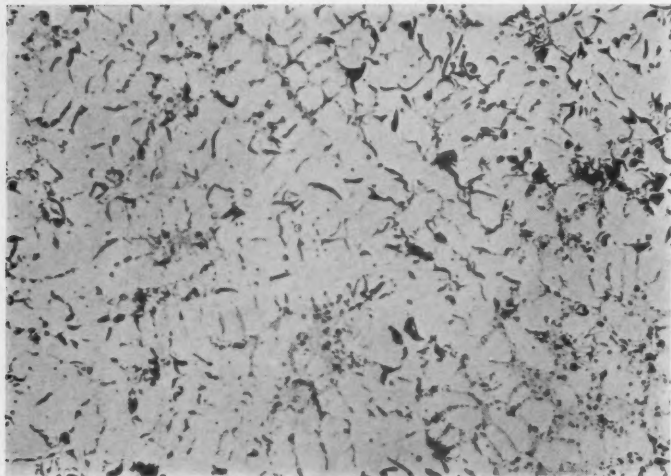


FIG. 29—UNETCHED—X100.

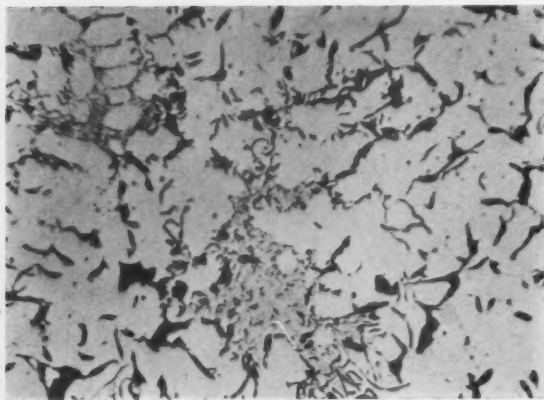


FIG. 30—UNETCHED—X100.

100. Fig. 35 (2000 dia. etched) is a typical pearlitic area from 3 in. dia. bar. Some of the "dirty" spots were examined, etched, and one is shown in Fig. 36 (2000 dia., etched). Some actual inclusions are evident. Also some black patches are seen, with cementite lamellae projecting into them. Some one (the writer believes R. M. Allen, but he has been unable to locate the reference) has shown a similar structure and suggested that the black areas are graphite. The writer does not think that that is the case in the sample shown by him.

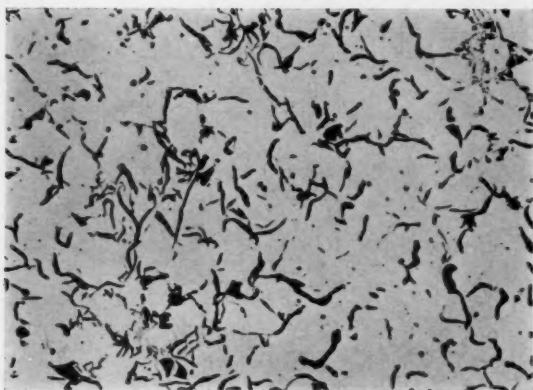


FIG. 31—UNETCHED—X100.

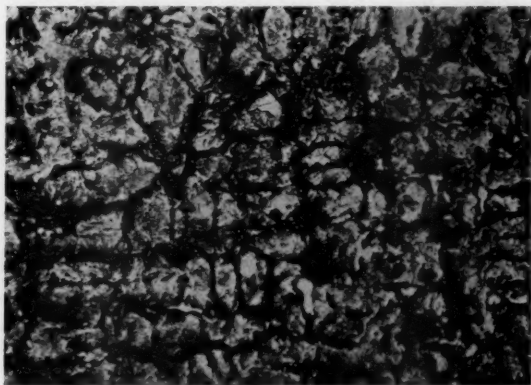


FIG. 32—ETCHED—X100.

Observation on Experiment

101. There are a number of things the above test tells us. We know the iron was distinctly hypoeutectic:

$$C_e = \frac{2.7 + (0.3 \times 2.3)}{1.00 - .027} = 3.48$$

When we cool this iron rapidly we have pseudo-eutectic graphite between originally primary austenite dendrites on the exterior of the bar and an admixture of pseudo-eutectic and flake graphite

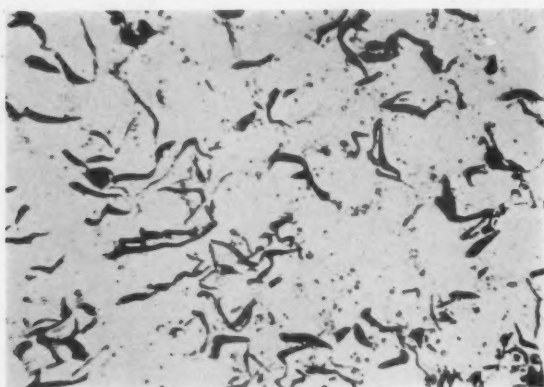


FIG. 33—UNETCHED—X100.

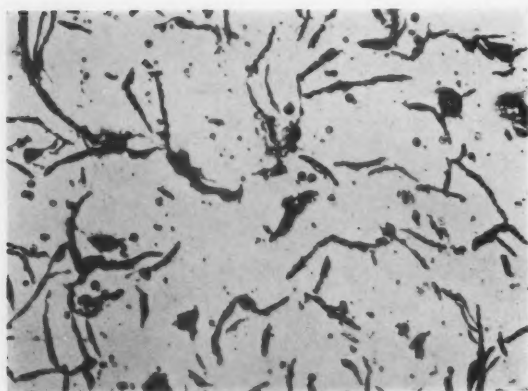


FIG. 34—UNETCHED—X100.

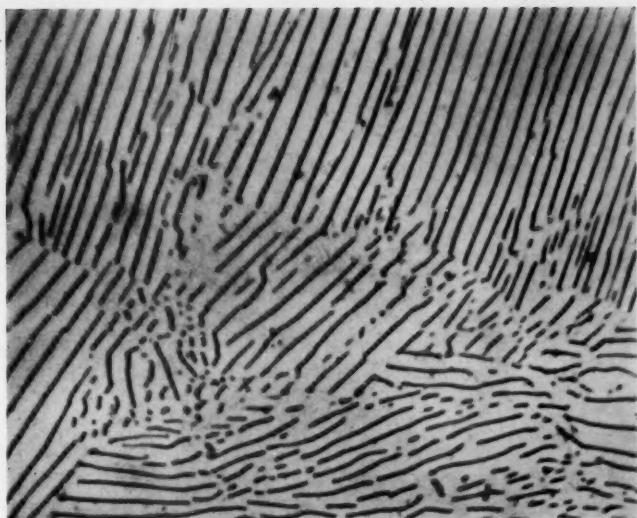


FIG. 35—ETCHED—X2000.

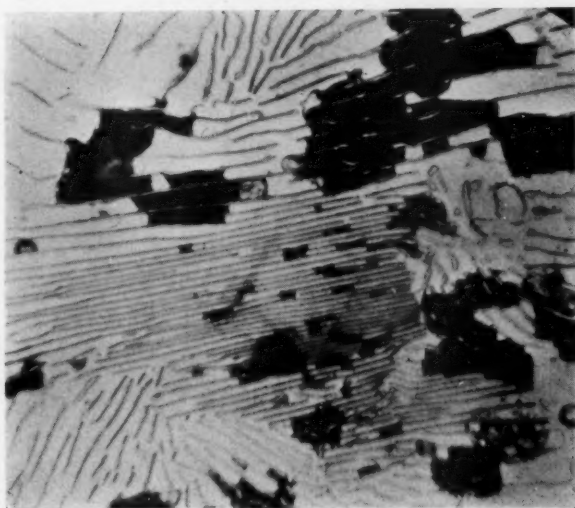


FIG. 36—ETCHED—X2000.

in the center of the bar. When cooled slowly as in a large section all pseudo-eutectic graphite is replaced by flake graphite.

102. Cooled rapidly, we have very clear cut evidence of originally fine dendritic formation. Cooled slowly, much of that evidence is less distinct, and from what remains it is shown that the residual dendritism is much coarser. The pearlite lamellae are more widely spaced when cooling is slow.

Concludes Cooling Rate Influences Groupings

103. A conclusion that may be drawn is that whether pseudo-eutectic or flake graphite occurs depends in this case on cooling rate, or in general on the "time factor." That in itself seems to be evidence against the many arguments that the pseudo-eutectic might be an actual iron-graphite eutectic. If cooling is rapid there is surfusion and fine dispersion. This is noted in white and in gray irons. When the decomposition of cementite, with resultant graphite, occurs at a low temperature, quite naturally the dispersion of the secondary precipitate is fine. May we not emphasize that the cooling rate is not the only thing that may alter the "time factor," and rate of reaction?

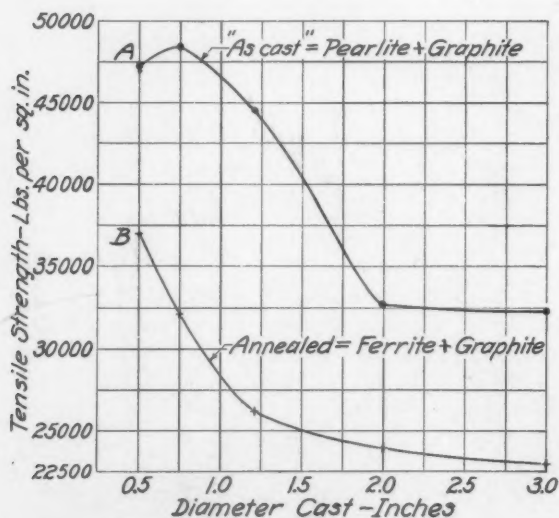


FIG. 37—TENSILE STRENGTH "AS CAST" AND "AS ANNEALED."

Relationship To Physical Properties

104. These structural changes are clearly revealed in the physical properties. Tensile strength "as cast" and as annealed are plotted in Fig. 37. At the 2 in. bar size and above structural changes are relatively complete, the pearlite in the "as cast" bars being a persistent component curve *A*. Curve *B* represents the stable condition (as of components) for this iron. In *A* the changing factors affected by time are

- (a) graphite distribution,
- (b) graphite flake size,
- (c) pearlite "grain size,"
- (d) fineness of pearlite lamination.

105. In *B* graphite has been increased about the same amount for each size bar, over *A*. (The amounts of graphite and combined carbon for *A* and *B* respectively are approximately constant over the range of bar sizes.) The distribution *B* versus *A* is not changed. The probable major significant variation in matrices in either of the sizes is the variation in fineness of lamination in the pearlitic series. Over curve *B* the differences in strength are largely proportional to the effectiveness of the graphite in promoting matrix discontinuity, i.e. to a "grain size" effect.

Properties Related To Structural Unstability

106. We at once see that the physical properties of a given iron are intimately related to its relative persistent unstability. In the more unstable condition for this iron tensile strengths of around 48,000 lb. per sq. in. are obtained, whereas in the most nearly stable condition a tensile strength of about 24,000 lb. per sq. in. is found.

Note—The writer does not mean to infer that because the components on *B* are stable (ferrite-graphite) the tests on that curve represent a really stable system, because it is evident that changes in strength are caused by changes in "grain size", using that term loosely.

107. Any factor which promotes persistent instability on the one hand or relative stability on the other then will influence strength. What we may call the "time factor" is important. In all our work we are juggling with rate and degree of reaction. Time, as in the present case allows reaction to become more complete. A change in the alloy, as for example, increase in carbon and silicon, would accelerate the rate of reaction. Nuclei (as inclusions) might change it, as would special processing, etc.

POURING TEMPERATURE EFFECT

108. Hypoeutectic iron similar in type to that just discussed was poured at different temperatures. As a specific example the following test is cited, metal from the same ladle, same sized bars and same molding practice:

Composition	Per Cent	Tensile Strength
Carbon	2.74	(A) Poured at 2620° F.—38,900 lb. per sq. in.
Silicon	2.25	(B) Poured at 2335° F.—31,550 lb. per sq. in.
Phosphorus	0.22	
Manganese	0.52	
Sulphur	0.056	



FIG. 38—UNETCHED—X100.

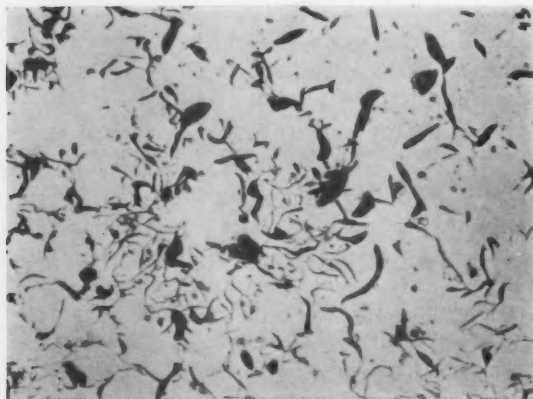


FIG. 39—UNETCHED—X100.

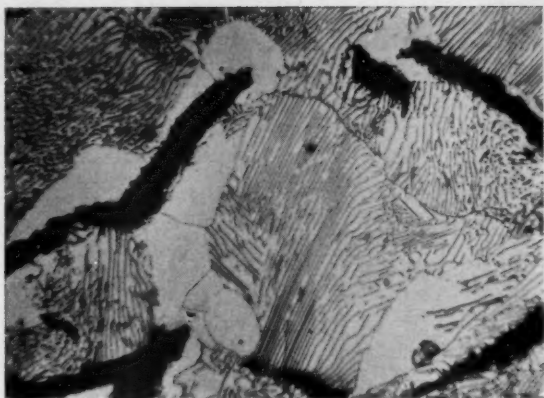


FIG. 40—ETCHED—X1000.

As shown in Fig. 38 ($A-2620^{\circ}\text{ F.}$) and 39 ($B-2335^{\circ}\text{ F.}$) the graphite structures are different, A being composed of rather well separated flakes, B showing residue of rosette formation. Bar B also has appreciable ferrite (local area shown at higher magnification in Fig. 40.) The cooling of B from pouring temperature to below the eutectoid must have been more rapid than that of A .

109. It is probable that 2335° F. , at which bar B was poured, is slightly below the liquidus for this iron. If that be the case some carbon segregation (micro) is likely and would readily account for the nature of the distribution and in part for the lower strength. The bar B appeared sound on micro examination.

Other Factors in Addition to Cooling Rate

110. The above emphasizes that cooling rate from moment of pouring to room temperature is only one of many factors which may influence the structure and strength of cast iron. Two typical formations of this type are shown in Figs. 41 and 42, magnification 500 diameters. The non-graphitic areas represent the residues of primary austenite dendrites. Similar type structures, at magnification of 1000 diameters, are shown as traced reproductions in Figs. 43 and 44.^a

^a Note—Reproductions were used to get more uniform intensities in darkness of flakes. The fine flake structure easily seen and traced on a heavy film, shows too indistinctly on printing and is unsuitable for reproduction on a printed page.

111. As may be noted in Fig. 43, the graphite close to the (originally) austenitic dendrite is finely divided, pseudo-eutectic type, while farther away coarser flake formation is seen. Actual differences in temperature over the area surely are slight. It would seem that the carbon concentration near the originally austenitic dendrite is lower than at some distance therefrom. It might then be agreed that, at higher concentration, the coarser formation was

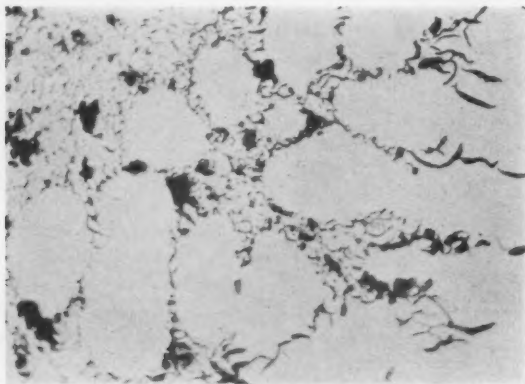


FIG. 41—UNETCHED—X500.

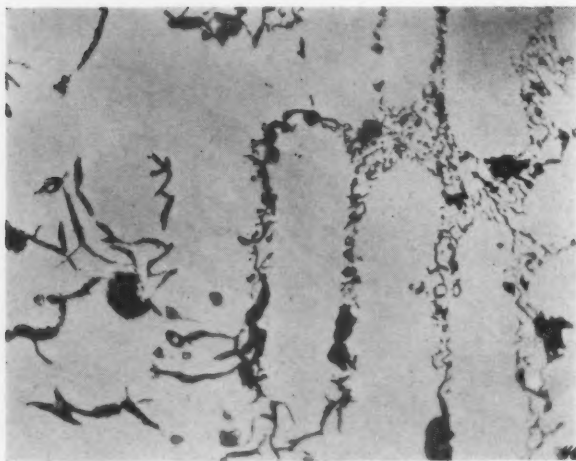


FIG. 42—UNETCHED—X500.

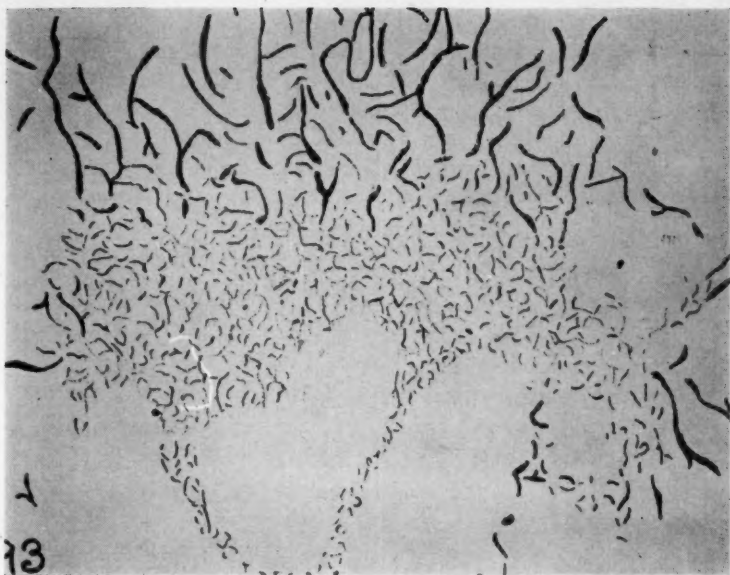


FIG. 43—REPRODUCTION AT 1000 DIAMETERS.

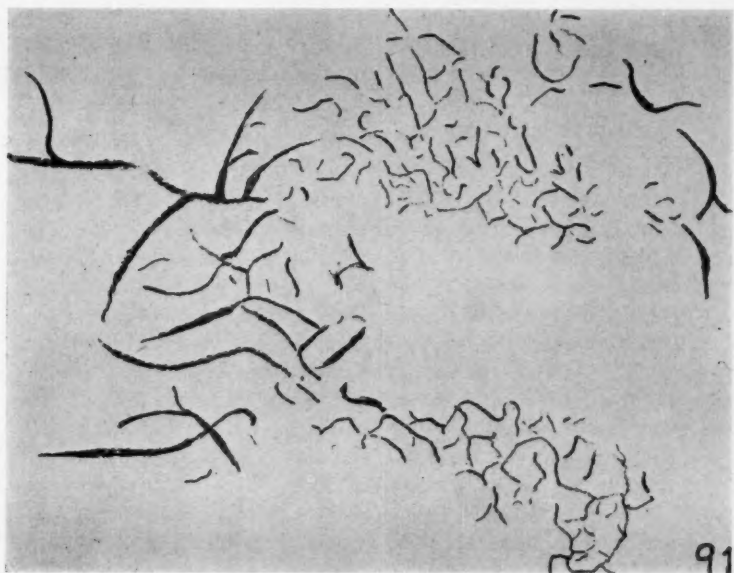


FIG. 44—REPRODUCTION AT 1000 DIAMETERS.

initiated first (in respect to temperature) and that the pseudo-eutectic formation, with its higher flake dispersion, was formed at a later stage in the thermal history. That would fit in with what has been noted relative to the higher dispersion of flakes due to rapidly cooling in more nearly eutectic type alloys.

112. According to those who adhere to the direct graphite precipitation theory and the existence of a graphite-austenite eutectic, it would seem that a structure such as Fig. 43 would require the preliminary precipitation of an eutectiform structure (believed by the writer to be a pseudo-eutectic, a secondary formation) and the agglomeration and growth of flakes at a temperature lower than that of initial formation. If temperature were held constant the tenability of such an hypothesis would be improved, but we are in this case dealing with a half inch diameter test bar which is cooling rapidly.

113. Fig. 44 shows somewhat more of the flake type structure.

Are Pseudo-Eutectic Flakes in Mesh Formation?

114. As one studies pseudo-eutectic structures it becomes apparent that the flakes are in a nearly continuous mesh; a condition that probably is related to Continental investigators observations that an extremely fine flake distribution may be undesirable mechanically. From the single diagram viewpoint, the possible continuity of the pseudo-eutectic flakes should not be surprising in view of the known continuity of cementite in the eutectic ledeburite.

PRELIMINARY SUMMARY

115. In the preceding pages some of the phenomena of graphitization that occur in gray iron were pointed out, in part because those are suggestive of the possible influences of inclusions, special treatments and the like.

116. Because of the marked effect on the continuity of the matrix, the amount, size, and distribution of graphite flakes greatly influence the mechanical properties. As has been pointed out by Everest⁴⁰ a pearlitic matrix in gray iron ordinarily is persistent over a wide range of compositions and cooling rates. Although persistent the grain size and the fineness of lamination of the pearlite may vary considerably, that being influenced by cooling rate and other factors. Pearlite ordinarily being largely persistent, the amount of graphite, with a given total carbon content, usually is rather constant. The effectiveness of the graphite then

is more directly related to its distribution, to the size of the individual flakes, and the nature of their groupings.

117. In fully liquid gray iron there is no real carbon segregation, that element being dissolved, probably largely as the carbide. There may be, and probably is, flotation of components, such as inclusions, which freeze above the liquidus of the alloy and which are lighter than it is. Such flotation, of inclusions, is more likely in the more nearly eutectic irons, because of their lower initial freezing temperatures.

118. Many of the differences observed in mechanical properties and microstructures of gray irons of similar nominal composition are traceable to factors influencing the rates of the graphitization reactions.

119. Gray irons may be considered as unstable but ordinarily persistent structures. At all times they tend toward assuming the stable condition; in terms of components at room temperature, ferrite and graphite; in terms of grain size, coarse particles dispersed in a matrix of coarse grained ferrite. To attain stability requires finite time, and as may be noted in large castings, long time. The time factor in approach to stability varies tremendously, according to the composition and treatment of the metal.

120. As time is increased (hence cooling rate decreased) ordinarily a given composition more nearly approaches a stable condition.

121. It is not necessary to consider an alloy as freezing in the so-called stable and meta-stable systems respectively to understand what takes place. An eutectiform (pseudo-eutectic) graphitization and one which is not eutectiform often can be produced in a given alloy poured from the same ladle and cooled at different rates. Undercooling and variations in degree of stability quite readily account for many cases of fine graphite dispersion. Time (or cooling rate) is a very important variable influencing graphite flake formation. However, it is evident that composition and other factors greatly influence rates of reactions, time or cooling rate being considered constant. In a sense these factors influence the final structures in ways somewhat analogous to cooling rate changes.

122. For example, the graphitization of a hypereutectic metal usually is more rapid than that of a hypoeutectic metal. The formation of "primary" graphite above the eutectic transformation in hypereutectic alloys is a "seeding" effect in part responsible

for the usual rapid graphitization of the alloy when passing through the eutectic temperature range.

123. Some of the possibilities are suggested in Table 1. That table is intended as a partial outline only.

Table 1

Cast Irons.

(A) DEFINITIONS

I—*Cast Irons*—essentially eutectiferous alloys of iron and carbon, plus various intentionally and unintentionally added "elements" and components.

(a) *Hypoeutectic*—Solidifying as primary austenite and eutectic.

(b) *Eutectic*.

(c) *Hypereutectic*—Solidifying as primary cementite (which decomposes readily) and eutectic.

(B) STABLE STATES

I—*Liquid*, iron plus carbon, latter largely as carbide.

II—*Below liquidus and above eutectoid temperatures*, austenite, a solid solution.

III—*Below eutectoid temperature*—ferrite and graphite. Ferrite has minute percentage of carbon dissolved.

(C) RELATIVE PERSISTENCE (ascending order)

I—*Primary cementite*, rapidly decomposes below liquidus and above eutectic, free graphite or "kish" formed in large flakes.

II—*Eutectic Ledeburite*.

(a) very readily decomposes in presence of free graphite, as in hypereutectic irons.

(b) may decompose rapidly or slowly in hypoeutectic irons, depending on composition, cooling rate and other factors.

III—*Pro-eutectoid cementite*—formed after ledeburite, and following behavior of that in persistence.

IV—*Eutectic pearlite*—a relatively persistent component, especially in commercial gray irons.

(D) FACTORS AFFECTING RELATIVE PERSISTENCE

I—*Cooling Rate*—rapid cooling rate does not allow time for reactions to reach equilibrium, hence often promotes persistence of unstable components. It minimizes diffusion, hence may promote segregation.

II—*Composition*—

(a) Increases in carbon content promote graphitization tendency. Increase in this tendency is most marked when the alloy exceeds the eutectic concentration. Segregation in nominally eutectic alloy may produce local hypereutectic areas.

(b) The addition of various elements may promote graphitization, others promote persistence of cementite formations in various ways, as partially illustrated in the following:

(1) Graphitizing elements (for example—silicon, nickel,

Table 1—(Continued)

- aluminum, etc.) may act in one or more of the following ways:
- Be contained within the carbide, promoting its decomposition.
 - Be contained in the matrix in such fashion that atom movement (as of carbon toward graphite) is facilitated.
 - Lower the eutectic carbon concentration.
 - Raise the eutectic transformation temperature.
 - Increase the intensity of thermal reactions.
 - Lower the thermal conductivity of the alloy.
- (2) Other elements (for example chromium, manganese, hydrogen, oxygen, etc.) may act in one or more of the following and other ways.
- Form mixed carbides more stable than iron carbide.
 - Obstruct carbon atom movement in the matrix.
 - Increase the eutectic carbon concentration.
 - Lower the eutectic transformation temperature.
 - Decrease the intensity of thermal reactions.
 - Increase the thermal conductivity of the alloy.
- (3) Promote on the one hand favorable nuclei conditions, and unfavorable ones on the other.

III—Temperature at Which Held Molten

Increase (superheating) usually lowers the temperature of the eutectic transformation—it promotes surfusion, within a certain range.

It lowers the viscosity of the molten metal and promotes flotation of solids.

It may change the degree of dissociation of carbon (high superheat).

It changes gas solubility.

It probably promotes reactions between some compounds and elements.

Low temperature melting as of highly graphitic gray iron suggests necessity for longer time for re-solution of graphite, and implies the retention of "dirt".

IV—Pouring Temperature

A high pouring temperature implies a slower overall cooling rate, and often greater diffusion. Reactions with mold materials will be more pronounced.

A very low pouring temperature may involve an alloy only partly liquid, and the likelihood of segregation. Also proper feeding and the production of a sound casting may be inhibited.

PART II

NOTES ON INCLUSION THEORIES

124. Gray iron is a reliable commercial material. With reasonable technical control it can be and is consistently made with uniform mechanical properties. As with other metals, a price of such uniformity is close adherence to constant and fixed manufacturing processes.

125. However, changes in types of raw materials, and particularly special processing may effect great changes in structure and hence in mechanical properties, even though nominal composition and cooling rates be little changed. There has been much speculation, and not a little experimentation to ascertain the causes underlying these phenomena. It is true enough that increases in metallurgical knowledge have made simple and clear many of the apparent anomalies which formerly puzzled us. It is equally true that there remains before us a great and little explored territory, the careful mapping of which will add greatly to our knowledge, and, concurrently, to improvements.

126. In attempting to explain many of these behaviors it is best to be frank with ourselves and to consider the various statements offered as hypotheses only. It is more probable that when even more evidence than is available at present is weighed and sifted it will be found that one simple explanation will not fill all cases.

Action of Superheating

127. Perhaps most argument has been centered about the process of superheating, because of the striking changes often produced by such treatment. Geo. K. Elliott showed^{1,2,3,5} that

- (a) increased strength resulted from superheating,
- (b) a possible "refining" action occurred,
- (c) the practical elimination of sulphur produced no striking effect (presence of Mn),
- (d) oxides and possibly nitrogen content may be lowered,
- (e) silicon did not produce the expected effect since "electric furnace iron will stand more silicon without opening up the grain,"

(f) superheating increased life and fluidity.

128. Some of Elliott's published data are given in Table 2.

129. It has been shown since that superheating is most effective in irons approaching eutectic concentration, and that there is an optimum temperature range for that treatment.

Effects, Mechanical or Chemical?

130. Today there are two main schools of thought. One claims that the effects are caused by the removal of extraneous bodies, inclusions. The other states that the carbide stability is raised by the presence of minute amounts of dissolved or absorbed elements, including gases. It is probable that there is merit in both hypotheses.

131. A recent handbook⁵⁰ defines inclusions as "particles of slag and dirt occurring in metal which were mechanically held during solidification." Another definition is "solid non-metallic impurities."

Supersaturation

132. If a liquid or a solid solution be cooled carefully often-

Table 2

PUBLISHED EXPERIMENTAL DATA OF G. K. ELLIOTT

Heat No.	Furnace Type	C %	Si %	Mn %	P %	S %	Calc. Equiv. Carbon (*)%	Change C %	Change Si %	Trans. Strength Lb.	Change Trans. %+
1221	Cupola...	3.48	1.92	0.56	0.53	0.069	4.28	.....	.....	2510	.....
	E. F.....	3.38	1.82	0.61	0.51	0.022	4.14	-0.10	-0.10	3670	42.2
1281	Cupola...	3.50	1.79	0.54	0.62	0.158	4.30	.....	.....	2470	.....
	E. F.....	3.22(a)	1.94(b)	0.54	0.61	0.052	5.04	-0.28	+0.15	3550	43.6
6271	Cupola...	3.35	1.91	0.72	0.59	0.091	4.16	.....	.....	3340	.....
	E. F.....	3.26	1.77	0.73	0.58	0.018	4.02	-0.09	-0.14	4550	36.2
1721	Cupola...	3.40	1.94	0.42	0.58	0.060	4.22	.....	.....	3210	.....
	E. F.....	3.41	2.21(b)	0.44	0.56	0.026	4.36	+0.01	+0.25	3760	17.1
8172	E. F.....	2.91	2.28	0.51(c)	0.55	0.013	3.80	.....	.....	3750	.....
8182	E. F.....	2.90	2.18	0.52(c)	0.40	0.057	3.49	.....	.....	4560	.....
3419	Cupola...	3.39	2.16	0.77	0.62	0.057	4.31	.....	.....	2510	.....
	E. F.....	3.14(d)	1.90	0.84	0.55	0.019	3.93	-0.25	-0.26	3410	35.8
2221	Cupola...	3.45	1.83	0.34	0.48	0.112	4.20	.....	.....	2950	.....
	E. F.....	3.38	2.30(b)	0.36	0.47	0.033	4.27	-0.07	+0.47	3580	21.3
1191	E. F.....	2.94	1.52	0.62	0.27	0.009	3.50	.....	.....	3700	.....

(a) Carbon reduced by mill scale in E. F.

(b) Ferro Silicon added in E. F.

(c) Ferro Mang. added in E. F.

(d) Reduced by steel addition.

(*) (C + 0.3 Si)

(100-10 P

times it is possible to produce a condition of supersaturation. A familiar metallurgical example is the supersaturation produced by quenching from an elevated temperature a solid solution nearly saturated with solute at that temperature, as for example in many of the so-called precipitation hardening or age hardening alloys, wherein the solute is less soluble at the lower temperature, but cannot readily precipitate because of the great increase in viscosity.

133. Many liquid solutions likewise can become supersaturated. It seems as though some little impetus or "kick" often must be given to initiate crystallization immediately upon passing the limiting solubility. Such an impetus is given by nuclei, small particles upon which crystallization can commence. Without nuclei being present surfusion and supersaturation may occur. In many systems there is a limit to supersaturation, a point at which spontaneous crystallization occurs.

134. The deliberate addition of nuclei often is called "seeding." Nuclei may be components of the system or mere extraneous material.

Graphite Nuclei Hypothesis

135. Many years ago Howe⁵¹ stated "that the presence of graphite nuclei should stimulate graphitization is only a single application of the general law that the presence of nuclei of the stable form hastens the change to this form from the metastable form, as nuclei of sodium sulphate dropped into a supersaturated solution induce extremely rapid crystallization." Piwowsky⁵² conceived the idea that in ordinary cupola melting, especially of highly graphitic pig iron, graphite flakes might not be completely dissolved, hence on cooling these would act as nuclei, promoting coarse flake formation.

136. Moldenke had observed the slower melting of graphitic as opposed to cementitic pig irons, and Piwowsky implied that the use of drastically chilled iron should be beneficial in obtaining fine flake structure. In particular, the postulate of Piwowsky and of Hanemann⁵³ was devised as an explanation of the finer flake structure found in superheated irons—superheat being thought to increase graphite solubility and hence to decrease the possibility of existence of graphite nuclei.

137. Piwowsky also advanced the thought that the reversal of the strengthening effect by excessive superheating might be due to a dissociation of carbide. Irresberger⁵⁴ claimed that "jolt-

ing of molten iron refines the grain by promoting more complete solution of possible undissolved graphite."

138. It has been noted, in American air furnace practice that holding iron molten for a long period tends to produce a fine grain size, which effect might be attributed to more complete graphite absorption. This also is indicated by certain of the experiments of Norbury and Morgan⁵⁵.

139. That graphite nuclei, if present, promote rapid graphitization at higher temperatures (hence coarser flake formation) seems well established. Mention has been made of the accelerative action of kish on the graphitization of the eutectic in hyper-eutectic irons. Norbury and Morgan⁵⁵ found that the addition of only 0.03 per cent flake graphite to an iron, with 3.41 per cent total carbon and 2.64 per cent Si. (apparently hypereutectic?) increased the flake size although the silicon content had been reduced to 2.29 per cent.

Graphite Very Soluble

140. It is very doubtful, however, whether graphite nuclei persist on complete melting of eutectic or hypoeutectic irons. Piwowarsky^{56, 57} himself showed that graphite dissolves very rapidly and completely in molten iron. Sauerwald and Korney⁵⁸ had arrived at the same conclusions a few years previously.

141. We may dismiss the persistent graphite nuclei hypothesis as inadequate for explaining all the differences between good cupola iron and superheated metal of like hypoeutectic or nearly eutectic composition. In a recent investigation, however, Di Giulio and White⁵⁹ claim that, in their experiment, graphite nuclei persisted in irons not superheated and that the differences between the "normal" and "abnormal" structures might be explained on that basis.

Extraneous Seeding

142. Rapid and fine crystallization in some supersaturated salt solutions can be induced by "seeding" with extraneous material—for example, the addition of a small amount of dust to a supersaturated solution of potassium permanganate may produce rapid and fine precipitation.

143. Such inclusions act as nuclei upon which crystallization initiates, and many cases of coarse grain structures in metals have been attributed to the presence of such inclusions. Steel especially

has received much attention, and in general, clean or "inclusion free" steel often is much finer grained and tougher than "dirty" metal. Considerable differences in mechanical properties are found with different deoxidation practices. It is not a purpose of this paper to discuss that field, but it is suggested that the reader will find much of interest and profit when reading papers on that subject.

Manganese Sulphide

144. The most common inclusion (existent above the eutectic temperature) in commercial cast iron is manganese sulphide. Such inclusions are shown in Figs. 45 and 46. Some excellent illustrations of this sort of inclusion were shown by R. M. Allen.⁶⁰ As a rule such inclusions in cast iron show some evidence of definite

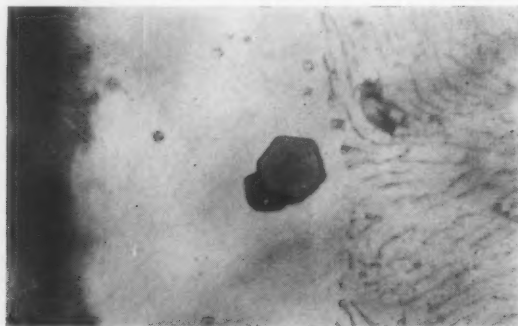


FIG. 45—ETCHED—X500.

crystalline form. Sometimes there is evidence that they are complex, having other components than manganese sulphide alone. The writer⁶¹ has shown that they quite often are contained within the graphite flakes. Roll⁶² has shown that manganese sulphide particles tend toward segregation in those portions of the metal last to solidify, namely between primary dendrites and toward the peripheries of granular eutectic structures.

145. In the presence of an excess of manganese it is assumed that practically all the sulphur is combined with that element. Because of its low density manganese sulphide often floats in the molten metal and high sulphur is found on the cope side. Boyles³⁴ found that iron sulphide, in manganese free metal, segregates to

the grain boundary positions, also that sulphur, in the absence of manganese, exerts a very potent influence on graphitization, including both some carbide stabilizing effect and the formation of a (coarse) flake graphite-pearlite structure.

146. Allison⁶³ has suggested that the precipitation of graphite is produced by the manganese sulphide crystals acting as nuclei. This viewpoint is disputed by Norbury and Bolton⁶⁴ who added manganese sulphide to "nuclei free" iron (i. e. iron which ordinarily would give very fine or pseudo-eutectic graphite structure) without perceptible increase in graphite flake size. Norbury and Bolton conclude that the nuclei effect of manganese sulphide is negligible.

Manganese—Silicon Ratio

147. F. J. Cook⁶⁵ described an inclusion in cast iron forming bright glazy patches. An apparent cause was a combination of high manganese and low silicon content, so that the percentages of each element were about the same. However, an analysis of such inclusions suggested that the material was largely slag from the cupola slag or from the refractories. An apparently similar defect is described by Le Thomas.⁶⁶

Microscope Gives Little Direct Evidence

148. Relatively little direct and visible microscopic evidence

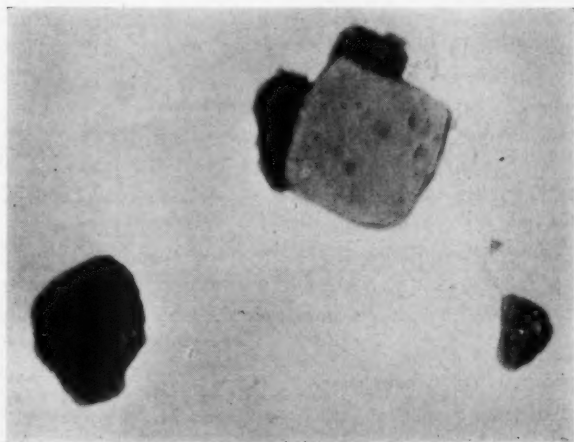


FIG. 46—UNETCHED—X3000

of the influence of inclusions on cast iron is available in the literature. A rough classification of inclusions as foreign and inherent might be made. Foreign inclusions might be thought of as those foreign to the melting stock and melting operations proper—as for example, particles of refractories, admixed slag, foundry sand, etc. Inherent inclusions might be thought of as small particles inherent in the melting stock, or produced therein by the action of gases, as by the cupola blast. Such a distinction necessarily is qualitative.

149. Foreign inclusions usually are large in size and are segregated locally. Most investigators consider that they are without much influence on the general graphitization characteristics of cast iron. Effective inclusions are considered to exist as very tiny solid particles in the molten metal, thus possibly acting as nuclei when the metal solidifies. As shown by Mahin and Lee⁶⁷ inclusions also may influence the loci of precipitates forming in the solid state.^r

150. Inherent inclusions are thought to be traceable to imperfect reduction in the blast furnace, and to the action of gases, such as oxygen, nitrogen, water vapor (and its products of dissociation, hydrogen and oxygen) the oxides of carbon and the like, and also to persistent compounds of aluminum, titanium, etc. which are not slagged off.

Oxygen Present

151. Since the time of J. E. Johnson⁶⁸ considerable attention has been given to the possible effects of oxygen, but until rather recently little was done to establish the condition in which the oxygen might exist. It is difficult to conceive oxygen existing except as oxides; metallic oxides, such as FeO, MnO, etc., non-gaseous, non-metallic oxides, for example silica, or as dissolved gases, as say carbon monoxide or carbon dioxide. Other gases, for example nitrogen and hydrogen may be absorbed in molten iron and under certain conditions held as unstable compounds.

152. It is difficult to consider the subject of inclusions and to avoid the general subject of influence of gases, but an attempt will be made.

^r Note—These investigators found that non-metallic inclusions affect locus of the free cementite network in hypereutectoid steels. The reference is cited as typical among many relative to the influence of inclusions upon changes occurring in the solid state.

Silicate—"Slime" Hypothesis

153. It has been thought that the presence or absence of silicate inclusions might furnish the clue to the differences in behavior of normally melted and superheated cast irons. Von Kiel and his co-workers^{69, 70} postulated the existence of a submicroscopic silicate "slime". Superheating lowers the viscosity of the metal hence should promote flotation and removal of silicates. Use of highly alkaline fluxes, for example soda ash, should help in removal of such inclusions. Adding ferro-silicon (which may form silicate readily) does not produce as fine grain structure as addition of silicon in the form of calcium silicide, the calcium probably preventing oxidation of the silicon. Superheating might produce an interaction between the carbon of the metal and the oxide formations, a self deoxidization as it were.

154. Mitsche⁷¹ suggests that silicate formation is likely whenever there is any iron oxide present. Scheil, Ruff and Schultz⁷² state that oxygen tends to increase the number of graphite nuclei.

155. The presence of oxygen in cast iron is well established. Many references to that fact, and also references to the behavior of oxygen containing iron are found in the literature. Some of the latter are conflicting. The mere existence of oxygen in various percentages in cast iron is not very illuminating, as it is necessary to know something about its association. Von Kiel and co-workers postulate a submicroscopic silicate (oxygen containing) slime, which hypothesis is not easily proved by direct methods.

156. Diepschlag^{73, 74} first stated that pig iron, produced under a silica rich slag, may be fine grained. Later he claimed that on remelting a high alumina slag tended to produce fine graphite as did high lime (CaO content), whereas high silica content tended toward production of coarse graphite. He also claimed that microscopically visible silica rich inclusions are unfavorable to fine flake formation.

Evidence Indirect and Incomplete

157. The evidence so far cited seems to need further rebuttal before any generalities can be drawn safely relative to the effects of silicate and other insoluble oxide inclusions, and fair evaluation thereof by a reviewer is difficult. Inclusions doubtless have some influence on the metal. However, it is only fair to point out that many oxides have a degree of solubility, including possible solubility in the structural components of the solidifying metal. In

such case a change in rate of graphitization could well be caused by say a slight solubility of iron oxide in cementite, increasing or decreasing the stability of that component. The mechanism of modifying processes in cast irons is not the only obscure one in the metallurgical field. Several instances could be cited from other alloy fields where the presence or absence of oxide inclusions, or of soluble oxides do not afford explanations of the mechanisms.

Vacuum Fusion

158. To eliminate the oxide factor several investigators have used vacuum fusion methods. Those remove oxygen, but also remove other gases, such as nitrogen and hydrogen. Piwowarsky⁷⁵, Hanson⁷⁶ and Boyles³⁴ found that vacuum melting produced fine (pseudo-eutectic) graphite, surrounded by ferrite.

159. That in itself is not direct proof on the oxide inclusion problem but it affords an interesting sidelight on the Japanese viewpoint that graphitization necessitates the presence of oxides of carbon.

"Fluid" Inclusions

160. Other investigators have added deoxidizers of various sorts. Among the most interesting of those researches is that by Norbury and Morgan.⁷⁷ Those investigators found that addition of 0.1 to 0.2 per cent of titanium and bubbling carbon dioxide through the melt completely refined the graphite structure of all hypoeutectic cast irons. They suggested that this treatment produces titanate inclusions which are extremely liquid when the graphite forms, and that being liquid they do not act as inoculants or effective nuclei. They believe that silicon and aluminum added to irons containing oxides produce solid and hence inoculating inclusions. Bubbling hydrogen through titanium containing melts coarsened the graphite structure. The authors considered that hydrogen reduced the iron oxide from titanate inclusions and raised their freezing points—i. e. converted them to solid, hence, inoculating inclusions. The foregoing experiments were made on $\frac{1}{4}$ lb. crucible melts. Similar type experiment did not work out on cupola melted metal; ladle treatment resulting in loss of titanium, and charged titanium, according to the authors, being subjected to reducing conditions in the cupola.

161. These authors state that in their experiments it was very difficult to introduce persistent inclusions by additions, such in-

clusions as staid within the metal probably being almost entirely generated by chemical reactions within the metal. That observation seems logical in that the latter named conditions should tend to produce more finely divided inclusions which, because of small particles size, have much less tendency toward flotation.

Sensitive To Hydrogen

162. Boyles³⁴ doubts the explanation of Norbury and Morgan relative to the liquid titanates, and believes that the real action of carbon dioxide is to free the melt from hydrogen. Boyles showed rather definitely that cast iron is very sensitive to hydrogen, and that hydrogen increases the stability of carbide in cast iron, within certain ranges promoting coarse graphite flake size. Boyles states that neither nitrogen nor oxygen is able to produce a change in size of graphite flakes. He says, "Assuming that the solubility of this gas (hydrogen) is a function of temperature many of the effects of superheating may be interpreted."

SUMMARY

163. One who has studied the literature of this subject would be rash indeed to come to any sweeping conclusions about the underlying reasons for the effects produced by superheating, the matter of heredity in cast irons, and various other apparent anomalies. What is cast iron? For convenience we may call it an eutectiferous series of alloys of iron, carbon, and silicon, containing, as cast, combined carbon not in excess of the eutectoid percentage, the matrix containing many graphite flakes. So far so good. But it is a series of alloys, and other constituents beside iron, carbon and silicon also must be considered. Manganese, phosphorus and sulphur, also "alloys" like nickel, are determined in routine analyses. But the "chemistry of minor constituents", as some one has called it, is very important; which we well know must be the case when we view what is being done in other alloy fields.

164. We know that the useful mechanical properties depend mostly upon the nature and continuity of the matrix. We know that the continuity of the matrix depends upon the amount, size and distribution of graphite flakes. We know (largely empirically) how to control fairly well the structure and to produce uniform and useful metal. In a qualitative way we know quite a bit about

some aspects of graphitization, but much, very much, remains to be firmly established.

165. Many attempts have been made to find out why, with given nominal analyses, various methods of processing produce different mechanical properties. Superheating versus cupola melting has been used herein as an illustration. Superheating may, and sometimes does, produce significant changes in nominal composition. At or near the eutectic concentration such changes must be viewed very carefully, in view of the possibilities of segregation. Let us dismiss that and consider those cases where hypoeutectic alloys are involved. Then:

Superheating decreases the viscosity of the metal.

It lowers the temperature of eutectic arrest.

Within ranges it promotes finer grain size and usually increased strength.

Many of the effects of superheating have been attributed to surfusion. Precipitations start at lower temperatures, which implies probability of higher dispersion.

166. Such surfusion might be considered to result from (a) a lack of nuclei (inclusions) upon which precipitation might start or (b) to an inherent stabilizing of carbide within a certain range. Most "explanations" vouchsafed are specific hypotheses based upon generalities (a) or (b) or (a) and (b).

167. Insofar as inclusions are concerned, the common hypotheses are:

(1) Graphite nuclei hypotheses of Piwowarsky, Hanemann and their co-workers. These are of doubtful validity for decidedly hypoeutectic irons, and in their original form, for cast irons in general.

(2) Silicate slime hypothesis, of Von Kiel and associates. This is attractive in many respects, but not proved directly—A submicroscopic slime cannot be seen. Circumstantial evidence is that higher temperature and lower viscosity may promote removal of the slime, as might other treatments also mentioned previously.

(3) Formation of fluid inclusions, or inclusions with fluid peripheries, this making the inclusions ineffective as nuclei, as postulated by Norbury and associates.

168. It cannot be denied that under certain conditions some of the premises of the above hypotheses may be valid. The writer

Table 3

Dia. Cast inches	Total Carbon %	C. C %	Dia. Pulled inches	Tensile (As Cast) lb. per sq. in.	Tensile (Annealed) lb. per sq. in. 1600° F.	Mod. Rup. (As Cast) lb. per sq. in.	Time* Min. Cool.	Sp. Grav. (As Cast)	Sp. Grav. (Anneal)	Shear lb. per sq. in. (As Cast) (.366")	Shear lb. per sq. in. (Annealed) (.366")
0.5	2.70	0.59	0.25	47,200	37,000	99,000	...	7.30	7.11	...	...
0.75	2.72	0.57	0.505	48,600	32,000	85,200	2.0	7.29	7.15	56,700	34,800
1.0	2.71	0.58	...	flawed	flawed	flawed	5.2	7.31	7.15	...	...
1.2	2.70	0.55	0.505	44,400	26,300	83,000	...	7.30	...	53,600	...
2.0	2.60	0.59	0.800	32,600	24,000**	77,000	26.0	7.44	7.21	48,000	34,900
3.0	2.51	0.56	0.800	32,300	23,000**	74,500	...	7.33	7.17	43,100	27,700

*from 2065° F. to 1350° F.

**0.505 dia. pulled.

appreciates the value of the work on inclusions proper, and recognizes the difficulties which confront the eminent investigators in that field. He trusts that it will not be considered ungracious to close with the comment that the case for inclusions is not proved, and the opinion that inclusion or nuclei action probably is not the sole explanation for the phenomena of variation in graphitization characteristics hereinbefore commented upon.

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DISCUSSION

Presiding: H. H. JUDSON, Foundry Supt., Goulds Pumps, Inc., Seneca Falls, N. Y.

CHAIRMAN JUDSON: This paper covers a very vital subject. We all agree that many of the properties of all of our irons, whether they be alloyed or not, are predicated on the amount and distribution of the graphite in the casting. Also, we might say that the success or failure of our castings in service depends upon the graphitization that has occurred within the casting, which makes this paper a very valuable one.

F. G. SEFING¹: (*Submitted as written discussion*) Concerning point 4 of the summary of points listed in paragraph 28 the writer believes that the author should not include the phrase "a very low percentage of silicon" without some qualifications. If a carbon content greater than 1.7 per cent is precluded in this summary, the writer believes that from the data on steels there is a state of equilibrium between eutectoid alloys with silicon (0.10 to 0.30 per cent) which will not precipitate graphite. The evidence, therefore, indicates that the silicon must be in excess of the 0.10-0.30 per cent in order to precipitate graphite even with a long time heat treatment to graphitize the carbon in the alloy.

In paragraph 143 reference is made to the "inclusion free steel often is much finer grained and tougher than dirty metal." From the general opinion held by steel metallurgists the presence of inclusions in a finely

¹ Research Laboratory, International Nickel Co., Bayonne, N. J.

divided state produces fine grain. It is not the quantity of inclusions but the wide distribution thereof that determines the grain fineness of steel.

It is unfortunate that the photographs showing "graphite" do not really show the graphite but merely the cavities, considerably enlarged, where the graphite had once been. In the writer's opinion a paper covering fundamentals of graphite inclusions in cast iron such as the author's paper should show the graphite as clearly defined inclusions.

DR. C. H. LORIG²: (*Submitted as written discussion*) This paper by Mr. Bolton ranks foremost among those dealing with that extremely involved subject, the technology of cast iron. The excellent manner in which Mr. Bolton sets forth his and the views of others is to be commended.

The technology of cast iron is still in its early stages of development. Naturally, our concepts of mechanisms, for example those concerning the solidification of gray iron and the formation of structural components within the iron, are likely to be many and often quite different in viewpoint. In paragraphs 62 to 65 Mr. Bolton sets forth, for illustration, various plausible though different mechanisms to account for the rosette and the whorl formations which are, as he states, the most typical structural arrangements of graphite in commercial gray irons. To lend support to one or the other mechanism it would appear necessary to establish whether or not flake growth and the precipitation of the pseudo-eutectic graphite occur simultaneously with or after solidification of the eutectic liquid has taken place while more precise information on the manner in which graphitization is initiated would help perceptively to single out the more probable mechanism.

A recent paper by Boyles* on the freezing of cast iron throws a good deal of light on the subject. In this paper the steps in the process of freezing hypo-eutectic gray irons seem to be very well established.

Graphitization and the formation of graphite structures in the eutectic cells were followed by examining the photomicrographs of specimens which were rapidly quenched while they were still partially liquid. The information obtained in this manner was summarized by Boyles as follows:

"1. Primary austenite freezes out in the form of dendrites which continue to grow down to the eutectic temperature.

2. Crystallization of the eutectic liquid begins at centers, which grow equally in all directions, forming a cell-like structure.

3. Segregation takes place in two stages: (a) between the primary dendrites and the liquid, (b) from the crystallization centers of the eutectic outward into the boundaries of the cells.

4. Constituents formed during the freezing of the eutectic occupy the interstices of the dendrites. The graphite flakes and the phosphide eutectic are thus restricted by the size and distribution of the dendrites."

These are statements entirely in harmony with our conception of

² Metallurgist, Battelle Memorial Institute, Columbus, O.

* A. Boyles, *The Freezing of Cast Iron*, Tech. Paper 809, A.I.M.E. Metals Technology, April, 1937.

freezing in a system such as the iron-carbon-silicon system, and while they may be general knowledge, it seems desirable to state them here because they reiterate the principles governing solidification of all hypo-eutectic gray irons regardless of the composition or the treatment given the molten iron. If they are kept in mind certain features of the rosette and whorl formations are not difficult to comprehend.

The various photomicrographs shown by Boyles are of further assistance. Five of these are reproduced here in Figs. 1A to 5A to show the growth of eutectic cells in an iron during the course of freezing. The iron, alloy No. 8, made from electrolytic iron, graphite and silicon carbide contained 3.49 per cent carbon, 2.01 per cent silicon, 0.007 per cent sulphur, 0.008 per cent phosphorus and no manganese. Although its composition with regard to manganese, sulphur and phosphorus contents was different from commercial gray irons, its behavior during freezing was not unlike the behavior of commercial gray irons.

Fig. 1A shows the structure after quenching from 2025° F. and heat-tinting. The structure has been magnified 20 times. Fig. 2A gives the details of structure in Fig. 1A at 100 magnification. Figs. 3A and 4A are similar photographs of the structure of a specimen quenched from 2010° F. and heat-tinted. Fig. 5A shows the structure of a slowly cooled specimen. It was heat-tinted and magnified 20 times.

The dendritic pattern in each photograph mark the position of the austenite dendrites which form in the early stages of freezing. The number and size of dendrites appear to be dependent only on the rate of cooling the iron and its composition. An interesting observation was that changes in melting practice seem to have little or no influence on the distribution of the primary austenite dendrites.

The eutectic cells form after the eutectic liquid has reached its crystallization temperature. They grow from centers within the liquid and finally absorb the liquid. Growth of the cells and the remains of unabsorbed liquid at the moment of quenching may be observed in Figs. 1A to 4A. The unabsorbed liquid is shown as the white constituent. The slowly cooled specimen, Fig. 5, shows the boundaries of the cells as a dark net-work.

The precipitation of primary austenite dendrites in liquid iron at temperatures above the eutectic but below the liquidus and the formation and growth of cells in the eutectic liquid at and below its initial crystallization temperature are common to the freezing of all hypo-eutectic gray irons. Aside from the fact that there may be more or fewer cells and dendrites developed, in a sense the microstructure of these irons are alike since they are composed primarily of the cells and the dendrites. Microstructural differences may exist, however, in the structure of the cells.

If changes taking place at the eutectoid temperature are disregarded, the principle differences between cell structures lie in the mode of occurrence of the graphite. All variations from very fine "eutectic" graphite to coarse flake graphite are possible and frequently both coarse and fine graphite may be observed existing in a single cell. Mr. Bolton has used the terms "rosette" and "whorl" to distinguish but two possible arrangements of the graphite in the cells. There, of course, are others, for it is

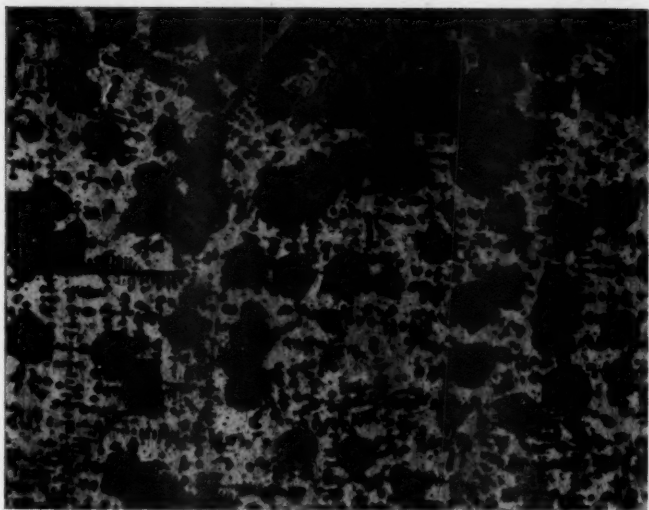


FIG. 1A—ALLOY No. 8. QUENCHED FROM 2025° F. HEAT-TINTED. X20.

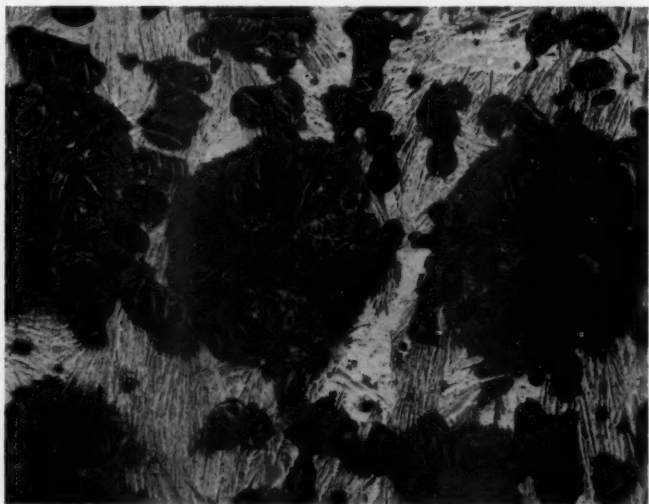


FIG. 2A—ALLOY No. 8. SAME FIELD AS FIG. 1A BUT ENLARGED SHOWING DETAILS OF CELL FORMATION. X100.



FIG. 3A—ALLOY No. 8. QUENCHED FROM 2010° F. HEAT-TINTED. X20.

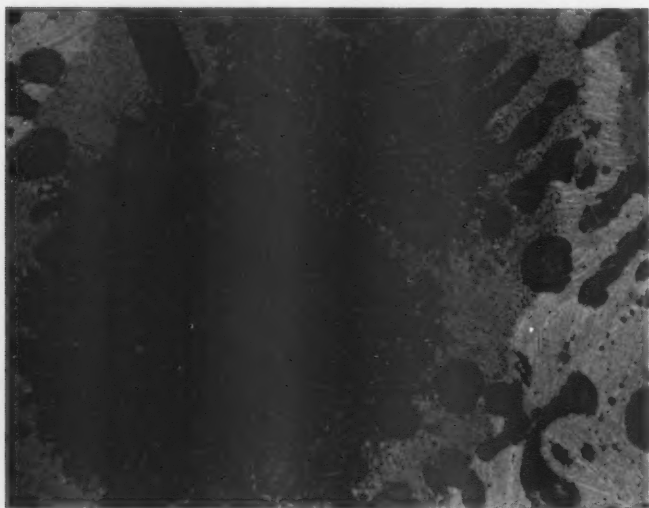


FIG. 4A—ALLOY No. 8. SAME FIELD AS FIG. 3A BUT ENLARGED SHOWING DETAILS OF CELL FORMATION. X100.



FIG. 5A—ALLOY No. 8. STRUCTURE OF SLOWLY-COOLED SPECIMEN SHOWING CELL BOUNDARIES AND STRUCTURES WITHIN THE CELLS. HEAT-TINTED. X20.

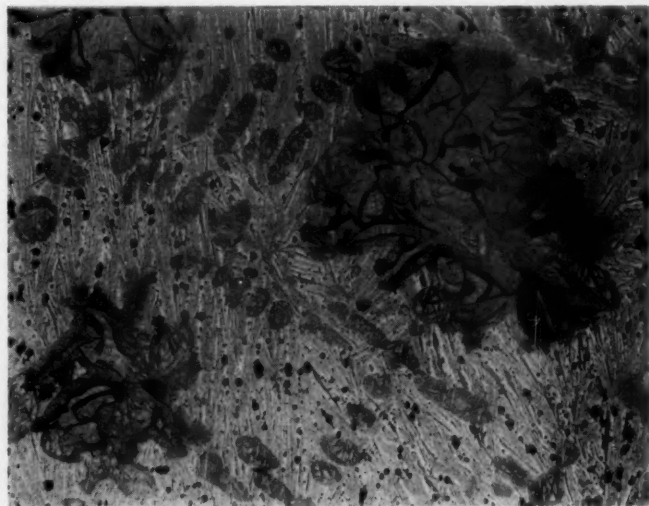


FIG. 6A—ALLOY No. 8, WITH SMALL ADDITION OF SULPHUR. QUENCHED FROM 2040° F. IT SHOWS THE BEGINNING OF THE GROWTH OF CELLS AND THE DEVELOPMENT OF COARSE GRAPHITE WITHIN THE CELLS. HEAT-TINTED. X20.

possible for all graphite in cells to be fine just as it is possible for the graphite to occur in alternate bands of fine and coarse particles or for coarse particles to exist only near the cell boundaries.

From what Boyles observed and recorded in Figs. 2A and 4A precipitation of the graphite must occur either simultaneously with or so closely following the solidification of the eutectic liquid one might consider without being seriously in error that the two occur simultaneously. For that reason it would seem improbable that flake growth occurs either by coagulation, so to speak, of fine graphite or by precipitation from solid eutectic cementite. The cores of the partially developed cells in the figures already contain fine graphite while coarse, flake graphite is shown radiating from the cores. It is important here to stress that these two forms of graphite existed in the cells before all the liquid had solidified and that the relative distribution of fine and coarse graphite remained the same in the slowly cooled specimen.

All cells do not necessarily show fine graphite in the core, even at the very beginning of their growth. Fig. 6A, for example, shows the beginning of cell growth in a specimen of alloy No. 8 quenched from 2040° F. to which a small amount of sulphur was added. The graphite in the cells is coarse.

Nothing is offered which would explain why the arrangements and size of the graphite should differ. The rate at which the iron is cooled is, of course, important, but there are other factors, among them the metal temperature and composition, the treatment the metal receives before pouring and probably surfusion, though it is likely to be of minor importance, that influence the formation of fine or coarse graphite fully as much as the rate of cooling. All of these appear to affect the relative stability of iron carbide which presumably affect the precipitation of graphite. Yet the fundamental causes for the precipitation of one or the other forms of graphite are not only very difficult to isolate, they remain unknown.

It is possible, however, to trace the separation of graphite in the growing cells. From the information cited and from others contained in the original article by Boyles it appears that the graphite in both the rosette formation and the whorl formation precipitate simultaneously with the solidification of the eutectic liquid. Seemingly, the two formations are substantially alike, except that the graphite in the core of the former is much finer. If graphite forms directly from the solidifying melt into fine particles or into flakes, as all the evidence seems to show, then the mechanisms mentioned by Mr. Bolton in paragraphs 62 and 63, and in the latter part of paragraph 64 are untenable. On the other hand, the statement appearing in the first line of paragraph 64, which reads, "a common conception of the whorl formation is that the center of the eutectic granule is the nucleus at which graphitization is initiated and from which flakes radiate" would seem to be substantiated.

MR. BOLTON: A question I would like to see answered is—why do we have flake formation? Perhaps Dr. MacKenzie can answer.

DR. JAS. T. MACKENZIE³: May I just be sure that we are thinking

³ Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.

about the same thing? You are conceiving that freezing starts from the austenite dendrite because the austenite must form first. Now, graphitization does not necessarily proceed from those centers. The graphite flake can start, as you say, from some periphery where the carbon concentration reaches a certain point and proceed inward in the crystal and outward into the liquid, can it not?

Mr. BOLTON: That is just the point. You and Dr. Lorig offer two variant hypotheses. I strode the fence and put both of them down.

There is another point here that is interesting to me, and one which I believe deserves checking. In paragraphs 49 to 51 we mention an experiment we ran. We took an iron whose eutectic temperature, as we know from other cooling curves, was 2066. We heated the iron up to 2000° F. The pyrometer was all right, the temperature measurement was all right, and the couple touched the specimen. It will be noted that, below the eutectic solidification point we got a re-absorption of graphite. The sample shown in Fig. 6 was originally a highly graphitized specimen before it was subjected to that treatment. There was plenty of flake graphite, yet in Fig. 6 (the quenched specimen) you see a few little dots, which may or may not be graphite.

If you will look at Fig. 7, cementite is evident. If our experiment was right, we formed cementite, below the eutectic.

A matter like this demands very, very careful checking. I do not want to be too positive, because the scientific approach demands checking and cross-checking. We could say, if that experiment be right, that in cast iron cementite formation precedes graphitization, and graphitization occurs at some lower temperature.

It also is interesting to look at a figure like Fig. 8. That is a closeup of some of that apparently largely cementite structure. Now, recalling that graphite occupies quite a large volume with reference to the other components in the matrix, notice at the left upper section of Fig. 8, around that cementite there is a very definite evidence of shrinkage, and it is evident in other portions of that figure and in Fig. 9. Also, to the right of center in that cementite particle there is an actual crack. It would seem that graphite was reabsorbed, the metal still was largely solid. Taking the graphite out and forming cementite, which does not occupy as much volume as its components of graphite and austenite, would signify that we still were working with an essentially solid iron.

A. L. BOEGEHOLD⁴: My impression gained from Fig. 8, showing this concave-sided area is that the graphite, in going into solution there, has actually melted that small area; that it had been taken above the eutectic solidification temperature there, and due to the concentration of the carbon in that particular place, (since it was all carbon to begin with,) you have really a hypereutectic area there. Then when it solidifies, you have some hypereutectic primary cementite in that small area. Of course, since it was a liquid, when it froze, it contracted in volume and left those voids around the outside of it.

Mr. BOLTON: If it was liquid at all, why would it leave voids?

⁴General Motors Research Laboratory, Detroit, Mich.

MR. BOEGEHOLD: It was liquid only in this particular small area, while the rest of the cast iron was solid.

MR. BOLTON: That is the difficulty with this particular experiment, you are so close to that point, although 65° or so would seem quite a bit.

DR. LORIG: Have you an idea how that cementite would break down again on slow cooling, at a rate similar to a casting?

MR. BOLTON: The only answer to that is, we did not try it.

DR. LORIG: It would form a flake graphite again.

MR. BOLTON: If that could be established by check, it would upset about 90 per cent of the beliefs of our continental investigators. I may say that there is in this paper a very clear explanation of the mechanism of fine graphite-ferrite formation that was shown in a paper* earlier this week. When you get the fine flake formation, the distances between flakes are very slight, the surface area of the flakes is very great, and so when you pass below the eutectoid, those combined circumstances (high surface area and short distances) assure the rapid precipitation of the remaining carbon as graphite, leaving fine graphite in a ferrite matrix. At a somewhat slower rate of cooling initial flake formation is greater, the distance between flakes is greater, surface areas are smaller, and, therefore, you find pearlite more persistent, until you get again into the very slow rates of cooling, where the stability tendency becomes quite apparent.

CHAIRMAN JUDSON: Referring to Fig. 17, we get that structure very often in a low carbon iron cast into a mold, a casting weighing 1½ tons, with a 2½ in. wall section, and the photomicrograph taken about one-half inch from the outside wall. We show that very often. That is quite extreme slow cooling.

MR. BOLTON: We usually find the ferrite bordering along those big flakes.

MR. BOEGEHOLD: Concerning Fig. 6, I believe it was said that that was a picture of an iron that was fairly well annealed, containing quite a bit of flake graphite.

MR. BOLTON: That was an ordinary gray iron with coarse flake graphite. It was heated to 2000° F., and quenched from there.

MR. BOEGEHOLD: The point I want to make is that when you re-dissolve graphite in the iron, why should the cracks where the graphite existed, heal, close up and disappear, because there is no force tending to push them together, to weld them together, and it does not seem to me as though you could get that healing unless you had actually caused a molten metal in there to get a continuous structure.

MR. BOLTON: The answer to that is Fig. 8.

MR. BOEGEHOLD: I have had this argument back and forth with some metallurgists as to whether you do close up those voids when you re-dissolve the carbon in solution, even at temperatures below the eutectic solidification point, the melting point.

* Ferrite—Its Occurrence and Control in Gray Cast Iron, R. H. Bancroft and A. H. Dierker, A.F.A. Preprint 37.9. Also Trans. A.F.A., vol. 45 (1937), pp. 449-458.

MR. BOLTON: With that particular iron, if we were appreciably above the eutectic solidification, it would have been as soft as mush and could not have been handled; it would have been bulged out. The temperature of the specimen may have been higher than we thought (although the couple touching it was correct). That is the reason I am saying this is interesting if you can get it checked.

DR. MACKENZIE: Wasn't there some phosphorus in there?

MR. BOLTON: A small amount.

DR. MACKENZIE: Whatever little there was would have been liquid at 2000° F.

MR. BOLTON: Yes, but there is a whole lot more of this cementite structure in here which probably has a little phosphorus in it, than could be confused with any real phosphorus formation.

DR. MACKENZIE: You show 0.41 per cent phosphorus for that.

MR. BOLTON: All right, then look at Fig. 7. If you are considering that as steadite, there is a lot of it for 0.41 per cent phosphorus.

MR. BOEGEHOLD: That is ledeburite plus the phosphorus that was in there.

DR. MACKENZIE: You would certainly have some liquid in there at 2000° F.

MR. BOLTON: The experiment should be repeated with a phosphorus free iron, as the effect of phosphorus confuses the issue somewhat.

J. S. VANICK⁵: Referring to Fig. 27, in Mr. Bolton's explanation, if I got it straight, he expected considerable graphite growth below the graphitization range. The illustrations are very good in showing that the slow cooling promotes the coarser flakes, but I gathered from Mr. Bolton's explanation that it was his belief that that coarsening took place quite a bit below the end of the graphitization temperature, let us say, and down to the eutectoid, rather than right within the graphitization range.

MR. BOLTON: The end of the graphitization range is lower. You get rapid graphitization up here to a certain point, depending upon the solubility of the carbon and in austenite, but the graphitization is tending to go on all the time, but much more slowly as temperature lowers.

MR. VANICK: Yes, but not flake growth, which is what I had in mind. These illustrations show quite a difference in flake length.

MR. BOLTON: In that experiment as shown in paragraph 108, there exists a marked difference in strength (the samples were sound). Undoubtedly the sample poured at the lower temperature cooled faster, because the mold condition was the same, and there was less heat to be abstracted from the casting. The second picture, Fig. 39, shows a tendency toward a rosette formation, or a finer flake formation, and was produced by the lower temperature pouring. I believe that what happened there is that in that case (lower strength) we were cooling rather slowly within the range of austenite formation, getting an actual separation of austenite, and then coming down below that range and cooling more rapidly. In

⁵ International Nickel Co., New York, N. Y.

doing that we threw the diagram over to the right. If this point represents the nominal eutectic composition, you can shift the line one way or the other. In other words, if we were to extend this liquidus line by surfusion, we would throw ourselves into a hypereutectic area. Surfusions may throw your eutectic position, in effect, by continuation of the line to the right. Nippert pointed out segregation by surfusion in cast iron.

Mr. BOEGEHOLD: We have a good instance of that in the case of white cast iron for making malleable iron, where we have primary cementite, which is probably formed by that same mechanism. Along with the primary cementite and right adjacent to it, we have the ledeburite which forms after the primary cementite forms and brings the composition back down to eutectic proportions.

J. W. BOLTON (*Author's written closure*): In reference to the discussion by Mr. Sefing, available evidence (Ref. Trans. Vol. 116 pp. 318-323 Iron & Steel Div. A.I.M.M.E.) indicates his position is incorrect, graphitization in low carbon alloys having been brought about with a very low percentage of silicon.

The term "inclusion free" steel is a relative term—implying to many the absence of appreciable amounts of microscopically visible inclusions but not precluding the possibility of a sub-microscopic slime. The question is one of terminology.

We disclaim any pretensions to ultimate perfection in polishing gray iron. Nevertheless we feel that Mr. Sefing's criticism is largely speculative. There is a lot of bunk about perfect polishing of gray iron to preserve exactly the cross sections of the flakes. Even to the uninitiated it is evident that perfection in this effort is not possible, for obvious reasons. It is easy to "open up" flake structures, or even to tear them out. Conversely it is easy to partially drag them over. The photomicrographs shown indicate the essential structural features and we venture the opinion that they possibly aren't quite as distorted as Mr. Sefing imagines.

We are indebted to Dr. Lorig for his illuminating discussion, and for his summary of the work of Boyles. The papers of Boyles and of the writer supplement one another in many respects, and it is pleasant to have part of the work of Boyles appear in the Transactions, where readers can study the several viewpoints brought out by the two workers.

A Study of Core Hardness

By H. W. DIETERT* and EARL WOODLIFF,** DETROIT, MICH.

Abstract

In an endeavor to determine upon some method of evaluating the quality of a baked core for use in a mold, the author has worked out a scratch test which gives valuable data as to the core's performance. The test measures what the author terms hardness. A standard test procedure is outlined. To determine the usefulness of this test, the author, after listing factors which affect the quality of a core, conducted an extensive investigation of hardness as related to these factors. The data obtained covered: (1) the effects of varying baking temperatures; (2) varying baking time; (3) varying moisture; time of standing of core before baking; (4) cooling time; (5) sand to oil ratio, and (6) effect of grain size. Definite conclusions drawn from the test data are listed.

INTRODUCTION

1. In usual foundry practice the surface hardness of a baked core, as determined in the past by the finger nail scratch test, is used largely to gauge the quality of a core. A soft surface core is desired where the core is to break down quickly, while a hard surface core is wanted when the core is to resist washing by molten metal. In this paper *this surface hardness of a core which resists scratching will be termed core hardness*. The purpose of the study reported here was to determine the many conditions that affect the hardness of a core.

FACTORS AFFECTING CORE HARDNESS

2. In the tests conducted, wherever possible, only one condition was changed at a time to determine the effect of that factor

*, ** President and Research Engineer, respectively, Harry W. Dietert Co.

NOTE: Presented before Sand Research Session of the 41st Annual Convention, Milwaukee, Wis., May 5, 1937.

in changing the core hardness. Factors which were studied consisted of the following:

- (1) Baking temperature.
- (2) Baking time.
- (3) Moisture content of the core sand mixture.
- (4) Time that the core was allowed to stand before being placed in oven.
- (5) Cooling time, or temperature of baked core.
- (6) Sand to oil ratio.
- (7) Fineness of core sand.

TESTING PROCEDURE

3. The properties of a baked core vary considerably as the sequence and times of operation are altered slightly. In order, therefore, to obtain accurate test results, the test procedure as outlined below was carried out in detail. This procedure is being considered by the A.F.A. Sub-committee on Core Tests as a possible tentative standard.

TEST PROCEDURE

3. Preparation of core mixture for permeability-strength-hardness tests.

(a) Apparatus required:

- (a) Laboratory drying oven.
- (b) Balance (sensitive to 2 mgs.).
- (c) Weights (2 kilogram capacity).
- (d) Beaker (50 c.c. capacity).
- (e) Beaker (1000 c.c. capacity).
- (f) Core test baking oven or shop core baking oven.
- (g) Mixing equipment (optional),
Laboratory size muller.
Laboratory size mixer or stirrer.
Bowl (glazed ware) (approx. 10 in. dia.)
for hand mixing.

(h) Burette and stand.

(B) Sand to be used in test is to be dried for two hours at 230°F. (For research test the A.F.A. standard silica sand is to be used. For plant control testing silica sands as used at plant may be used.) Full description of the sand used is to be recorded with test data.

(C) Weigh out a 2500 gram sample of dried cool sand in a 1000 c.c. beaker.

(D) Weigh out the desired quantity of cereal binder, if such is to be used, and add to the mix. Mix for a period of two minutes.

(E) Place the sand sample in the mixer and add sufficient water to temper the mix as desired. Water added is measured with the burette. (This makes it possible to add definite percentages of moisture to the sample.) Operate the mixer for a period of two minutes. When sand is mixed by hand, place the sample in the bowl. The sand sample is to be rubbed between the palms of both hands using the same timed procedure as is used in machine mixing.

(F) In research tests a sand to oil ratio of 100 to 1 by weight (which is substantially 60 to 1 by volume) is to be used. In control tests other ratios may be used. The ratio used is to be recorded with the test data. Where the standard 100 to 1 ratio is used, 25 grams of oil is weighed. The procedure to be followed in weighing is to first fill the 25 c.c. beaker with some of the oil to be tested. Then pour out this oil, holding the beaker at a 45 degree angle. Hold the beaker

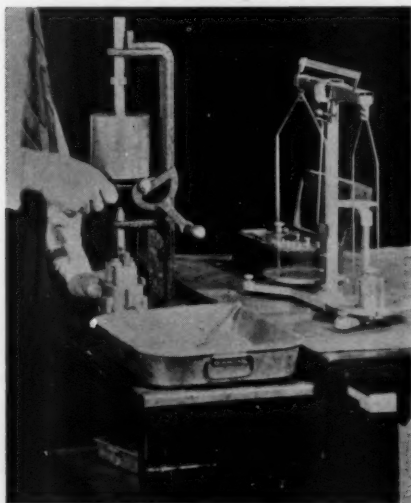


FIG. 1—RAMMING TENSILE CORE SPECIMEN WITH A.F.A. SAND RAMMER.

in this position for one minute; timing with stop watch. Then place the beaker on the left hand pan of the balance and place sufficient weight on the right hand pan to balance the beaker. Next add 25 grams of weight to right hand pan of balance. Pour sufficient oil into the beaker to balance. The oil is then poured on top of weighed sand sample, holding the beaker at a 45 degree angle. Hold the beaker in this position for one minute. Operate mixer for a period of four minutes.

(G) The first batch mixed is discarded for the reason that some of the oil is absorbed by the metal parts of the mixer or mixing bowl. Make a second batch and use this sand for test sample.

(H) The test samples are made as outlined in "A.F.A. Standards for Testing and Grading of Foundry Sands," (1931 edition).

THE INVESTIGATION

Equipment

5. The test equipment used in this investigation conformed to the A.F.A. specifications on core testing. The sand, water and oil were mixed in a laboratory sized Baker Perkins type mixer.



FIG. 2—BAKING TEST CORE SPECIMENS IN CORE TEST OVEN.

6. The test core specimens were rammed with a standard sand rammer (Fig. 1). The plunger of the tensile core box was clamped to the plunger of the rammer with the core box being removable for filling with sand, and for removing core from box.

7. The cores were baked in the core test oven illustrated in Fig. 2. The oven is uniformly electrically heated and controlled within $\pm 2^{\circ}\text{F.}$ to any desired baking temperature up to 600°F. Test cores were placed on a revolving table which is raised into the baking zone. By lowering the core shelf to the small door level, cores may be removed at intervals without disturbing the baking temperature existing in the oven.

8. The core hardness of the baked cores was determined with the core hardness tester illustrated in Fig. 3. A load of 700 grams is applied to the diamond pointed tool which is engaged with a dial indicator showing the depth that the diamond point protrudes beyond the flat face of the tester. The tester is pressed against and pulled along the flat surface of a core. The softer the core, the deeper will the diamond point scratch the core, and the

Table 1

RANGE OF HARDNESS READINGS

Dried molds, soft.....	20
Dried molds, hard.....	40
Baked cores, soft.....	35
Baked cores, medium.....	50
Baked cores, hard.....	75
Baked cores, very hard.....	90



FIG. 3—CORE HARDNESS TESTER. THE DIAMOND POINT IS SHOWN PROTRUDING FROM THE BOTTOM OF THE INSTRUMENT.

lower will be the reading on the dial. Table 1 gives some representative readings on cores and molds.

9. The tensile strength of the test cores was determined with a sand strength machine equipped with a tensile core accessory as illustrated in Fig. 4. Strength readings were recorded in pounds per square inch and are average readings on these tests.

10. The permeability of the cores was determined on the A.F.A. standard baked specimen (2 in. in diameter and 2 in. long) with the aid of the core permeability tube and permeability meter.

Materials Used

11. The core oil used in the investigation was a commercially compounded core oil of linseed base. The core sand used in all tests, with the exception of the grain fineness effect test, was a Michigan City lake sand mined in the lower western portion of Michigan. A fineness distribution curve of this sand is shown in Fig. 5.

EFFECTS OF VARYING BAKING TEMPERATURE ON THE CORE HARDNESS

12. The temperature at which cores are baked influences both the surface and the interior of a core. The surface condition of the core is measured by the core hardness, while the tensile strength of the core indicates the condition of the interior. Test cores baked in the core test oven bake more rapidly than cores in production primarily due to the perfect baking condition obtained in the test oven. The core hardness, tensile strength and permeability of test cores baked at various temperatures under varying baking times are shown graphically in Fig. 6. The numbers shown after core property are the length of baking time. For example, hardness 3 shows that the core was baked three hours.

13. A study of the hardness curves, Fig. 6, clearly shows that a baking temperature of 350° F. produced the maximum hardness when the time of baking was one and one-half hours. High baking temperatures, in all cases regardless of baking time, produced the lowest core hardness. Baking temperatures below 375° F. gave best results in producing a firm surface or high core hardness.

14. The tensile strengths of cores behave in the same manner as core hardness in that temperatures above 400° F. produced low tensile strength cores regardless of baking time. Strongest cores

were obtained at 350° F. baking temperature with a time of one and one-half hours.

15. The permeability of a core is not affected by the baking temperature.

EFFECTS OF VARYING BAKING TIME ON THE CORE HARDNESS

16. A very similar set of test curves to that of Fig. 6 is obtained when the baking time is varied for different baking temperatures as shown in Fig. 7. The hardness of the cores increased as the baking time was increased up to substantially two hours, as long as the baking temperature was not above 400° F. With temperatures above 400° F., the core hardness shows a decreasing

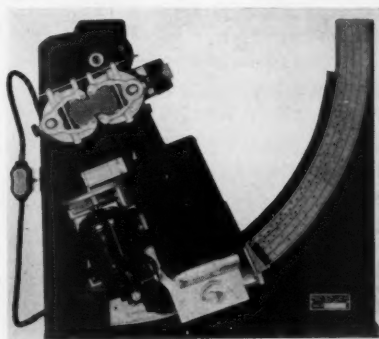


FIG. 4—TENSILE STRENGTH OF BAKED CORES DETERMINED WITH UNIVERSAL SAND STRENGTH MACHINE. TEST CORE SHOWN IN HOLDER.

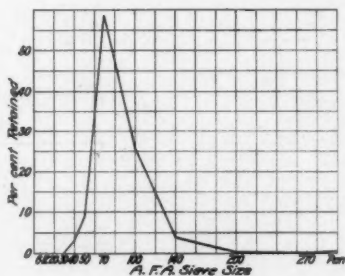


FIG. 5—GRAIN DISTRIBUTION CURVE—MICHIGAN CITY SAND FINENESS No. 56.

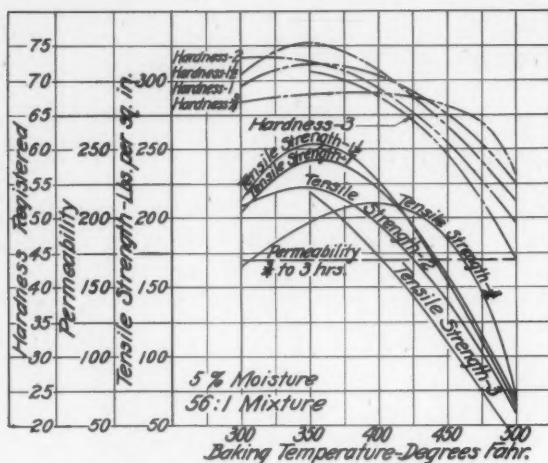


FIG. 6—EFFECT UPON STRENGTH AND HARDNESS OF BAKED CORES WHEN BAKING TEMPERATURE IS VARIED.

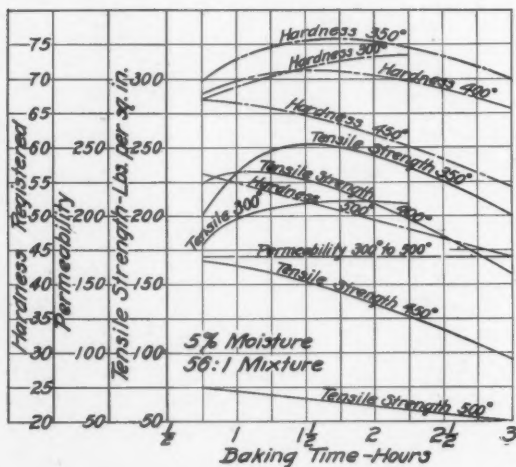


FIG. 7—EFFECT UPON PROPERTIES OF THE BAKED CORES WHEN BAKING TIME IS VARIED.

trend, regardless of how short the time of baking may be.

17. The tensile strength of a core follows the trend of core hardness as the baking time is varied. The advantages of temperatures lower than 400° F. is clearly shown in Fig. 7.

EFFECTS OF VARYING MOISTURE CONTENT ON THE CORE HARDNESS

18. A baking temperature of 350° F. with a baking time of one and one-half hours was used in studying the effect of moisture in the core mixture. The curves plotted (Fig. 8) illustrate how the hardness, tensile strength and permeability change with a change of the moisture content of core sand mixtures. The core hardness increased as moisture content increased up to 6 per cent for the Michigan City sand used. When the moisture was increased beyond 6 per cent, the hardness decreased slowly. This indicates the desirability of using moisture control to secure cores of uniform hardness.

19. The tensile strength curve shows a maximum at zero moisture and a second peak at 6.5 per cent moisture. Core mixtures tempered with insufficient moisture will result in low strength cores. The permeability of a core is slightly affected by moisture content of the mix as shown in Fig. 8.

EFFECTS ON CORE HARDNESS OF STANDING IN AIR BEFORE BAKING

20. The rammed specimens were allowed to stand in the air for periods varying from zero to six hours before baking. The test results from this series of tests are shown in Fig. 9. As may be assumed, the core hardness decreases as the length of time in-

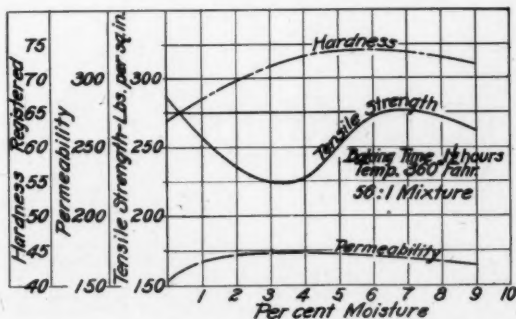


FIG. 8—CURVES SHOWING EFFECT OF VARYING MOISTURE ON PROPERTIES OF BAKED CORES.

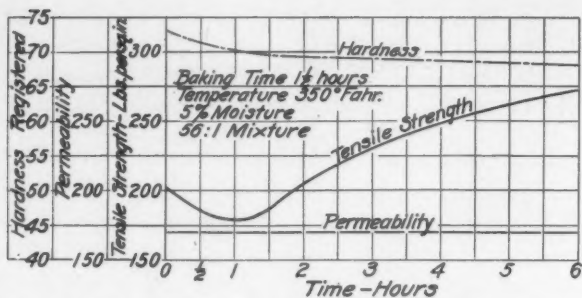


FIG. 9—EFFECT ON PROPERTIES OF BAKED CORES WHEN GREEN CORES ARE ALLOWED TO STAND IN AIR BEFORE BAKING.

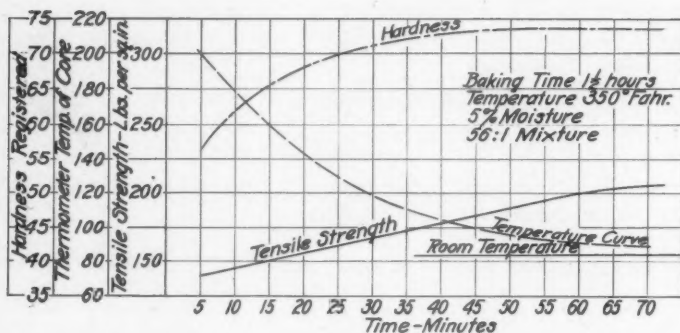


FIG. 10—RELATION OF CORE STRENGTH AND HARDNESS WITH COOLING TIME.

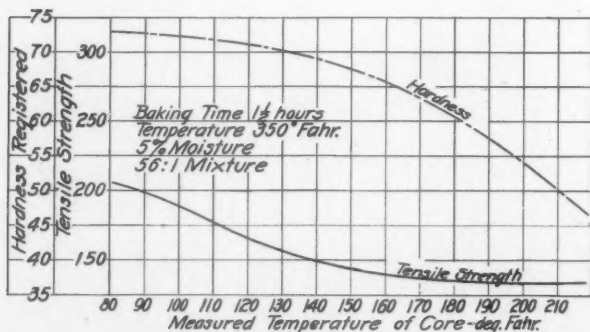


FIG. 11—CURVES SHOWING DEVELOPMENT OF STRENGTH AND HARDNESS OF THE BAKED CORE WHILE COOLING.

creases before cores are placed in the oven. Cores placed in the oven immediately after ramming produced a hardness of 73, while those allowed to stand six hours possessed a hardness of 68.

21. A marked change in the tensile strength of the cores was secured as the length of standing time was varied. Cores placed in the oven immediately possessed a strength of 200 pounds, but if allowed to stand one hour, the strength decreased to 180 pounds. As the length of standing time was increased beyond one hour the strength increased. A strength of 270 pounds was secured when the standing time was six hours. Moisture in the cores was apparently reduced to practically zero which gave the maximum strength. Cores made with zero moisture (Fig. 8) gave a strength of 275 pounds.

THE EFFECTS OF COOLING TIME ON THE CORE HARDNESS

22. Cores in a foundry are often used while they are still warm. The practical man realizes that the strength and the hardness are much lower when the core is still hot or warm. The relation between the cooling time and the strength and hardness is shown graphically in Figs. 10 and 11.

23. The hardness of test cores, after cooling five minutes in a room (temperature 83° F.), was 56 and after cooling seventy minutes, the hardness was increased to 73.5. The tensile strength for the same range of cooling times increased from 180 pounds to 205 pounds. The surface temperature of the cores for five minutes cooling was 200° F., and for seventy minutes cooling it was 84° F. The curves of Fig. 11 show clearly the relation between the temperature of the core and hardness and strength.

24. When the temperature drops from 200 to 84° F., the strength of the core increases 14.8 per cent and the hardness increases 31 per cent. This increase in both strength and hardness shows the importance of allowing the core to cool before handling in order to decrease core breakage.

THE RELATION BETWEEN SAND TO OIL RATIO AND CORE HARDNESS

25. Increasing the oil in a core sand mixture for cores naturally increases the strength and hardness. The rate at which the strength and hardness increase is shown in Fig. 12. The hardness increases in a straight line function, while the strength increases

in a parabolic function. In percentage, the strength increases faster than the hardness.

26. The permeability of a core decreases as the amount of oil is increased. A core made from 70:1 sand to oil ratio by volume

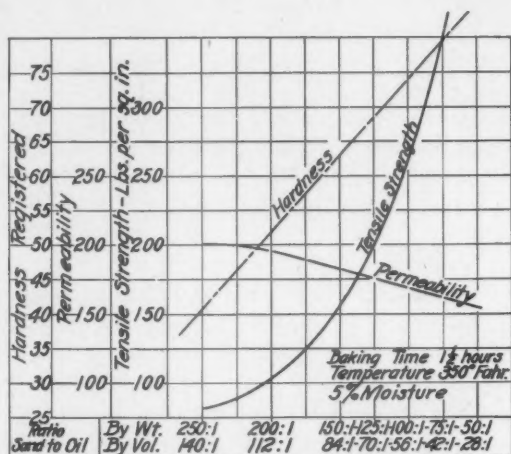


FIG. 12—PROPERTIES OF BAKED CORE WHEN SAND TO OIL RATIO IS VARIED.

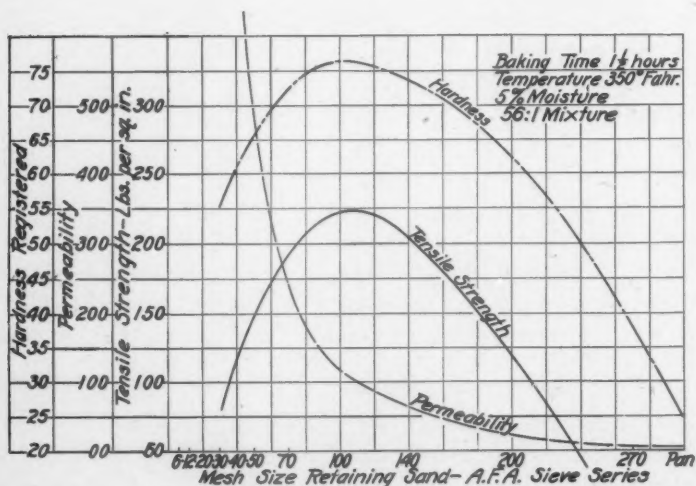


FIG. 13—CURVES SHOWING PROPERTIES OF THE BAKED CORE WHEN GRAIN SIZE OF THE SAND IS VARIED.

showed a permeability of 175; while one made from a 28:1 ratio had a permeability of 155, a decrease of 11.4 per cent. Changing the amount of oil did not materially affect the permeability. It will, however, materially increase the amount of gas generated. Doubling the amount of oil in a core mixture will substantially increase the strength 150 per cent and increase the hardness 50 per cent.

THE EFFECT OF GRAIN SIZE ON CORE HARDNESS

27. Core sand that varies in fineness is frequently used. The effect a change in fineness has on the hardness, strength and permeability is shown in Fig. 13. Test cores were made from sand which consisted wholly of a certain sieve size, this ranging from thirty mesh to pan material.

28. It is of particular interest to note in Fig. 13 that 100 mesh material gave the hardest and strongest cores. An increase or decrease in grain size resulted in a material decrease of hardness and strength. A core made of this grain size gave a permeability of 107, a hardness of 76 and a strength of 222 pounds.

29. Cores made from 270 mesh and pan material possessed practically no strength or hardness. The most economical core sand from a standpoint of strength and hardness would consist of sand grains ranging from 70 to 140 mesh, preferably all 100 mesh, when the core sand mixture is tempered to 5 per cent moisture and a linseed base core compound is used.

CONCLUSIONS

30. The relations found in this study show that the core hardness is affected by the manner of core treatment before, during and after baking.

31. Conclusions that we reached as to conditions influencing core hardness are:

(1) A baking temperature of 350° F. produced the greatest tensile strength for the type of core oil used. Different compositions would undoubtedly require different temperatures. It may be stated that it would prove most economical to determine the baking temperature which produces the maximum hardness and strength to allow the use of the minimum quantity of core oil.

(2) The maximum hardness and strength were obtained with a baking time of one and one-half hours when a temperature of 350° F. was used. This short baking time cannot be used as a

criterion for baking cores in the foundry. The test, however, shows clearly that the length of baking time materially affects the core hardness.

(3) Temperatures lower than 375° F., regardless of the baking time, produce the strongest cores.

(4) The permeability of a core is not affected by the baking time or temperature.

(5) A core should be cooled to a temperature near 80° F. to permit it to obtain maximum hardness and strength before handling.

(6) The tensile strength of a core increases at a faster rate as the quantity of core oil addition is increased. The permeability of the core decreases under such conditions.

(7) The sand grains of a core sand when retained on sieves 70, 100 and 140, preferably the 100 mesh sieve, produce a core of maximum hardness and strength. Sand grain size should be changed from this size only as necessitated by finish of core surfaces and availability of sand.

(8) The hardness of a core increases as the moisture content of the core sand mix is increased.

(9) The strength of a core is maximum when zero moisture is present in the mix. A second high strength point was obtained when using Michigan City sand and the mix contained between 6 and 8 per cent moisture. Working the sand at a low moisture should be avoided in that the strength will be low.

(10) The permeability of a core is lowest when zero water is present in the sand mix, for in this state the sand grains pack tightly together.

(11) Cores with maximum core hardness are obtained when they are placed in the core oven immediately after making, as this avoids drying of the outer surface of the cores.

(12) Cores of maximum strength are obtained when they are allowed to stand in the core room for a period of six hours before baking.

(13) The permeability of cores is not affected by length of time standing in the room before baking.

DISCUSSION

Presiding, R. F. HARRINGTON, Hunt-Spiller Mfg. Co., Boston, Mass.

H. A. DEANE:¹ Mr. Dietert, in your test procedure, where the oil is measured, why not weigh the oil? In this way you will be more certain of the amount than in your method of pouring it out for one minute. You weigh the oil anyway so why not get the specific gravity of it with a hydrometer and then weigh it?

We believe that our method is more accurate and faster than the one you describe. As our oil-to-sand ratios are by volume, we use volume proportions. We secure the specific gravity of the core oil with a hydrometer and figure the weight of the volume of oil we wish to use. The oil is weighed in a watch glass on a sensitive balance. It is then transferred to the core sand mix by pouring most of it. The oil remaining on the watch glass is rubbed off with some of the dry sand that is used in the core sand mix. This procedure is faster than the one described in the paper. We think it is more accurate because there is less human element involved than in tilting the beaker at a 45 deg. angle for one minute.

MR. DIETERT: The test procedure may be briefed too much so that the exact method used is not clear. The oil that was used per batch was weighed on a sensitive analytical balance. We take a small beaker, fill it with oil and then turn it over to a 45 deg. angle and let all the oil run out that will run out in a minute's time. Then the surface of the beaker is covered with oil. We place the beaker back on our balance and weigh out the quantity of oil that we want, and then empty it again in the same manner. The film of oil retained on the beaker is the same in each weighing.

HAROLD NORDAL:² We have taken sands and separated them into their individual grain sizes. In other words, we have taken the sand, screened it and kept the sand from each screen separate. We ran the strength test on each screen size and found that the strongest core is obtained from the sand left on the screen on which the bulk of the sand remained. I was wondering if Mr. Dietert had any information on this point? In other words, if the bulk of a sand is of a 70-mesh, we find it has a greater strength. If it is of the 100-mesh, we find that has the greater strength. That is true except with Ottawa silica sand which showed the fine grains to be strongest.

MR. DIETERT: I have never tried that scheme and therefore have no information on that point.

MEMBER: In many foundries, it is the practice to make stock cores, both light and heavy. Some of the sand stands for hours and some stands for days. No matter how carefully you make your mix or do your baking, there may be some physical condition taking place while those cores stand over a long period. The question I want to have answered is whether or not these cores would be affected by atmospheric conditions when not used within an hour or so?

¹ Metallurgist, Deere & Co., Moline, Ill.

² Sand Control, Fairbanks Morse & Co., Beloit, Wis.

MR. DIETERT: I would say from experience that the soft cores would be affected more by the atmospheric conditions than the hard cores. Naturally, the stronger the core, the longer you can let it stand, and still be able to use it. The core which is somewhat over-baked will withstand atmospheric effect better than one that is slightly under-baked, particularly so if you are using cereal binders with the core mix. However, this is not a matter of a few hours time but several days.

MEMBER: Mr. Dietert mentioned that there has been quite a bit of argument as to whether the oil or the water should be put in the sand first. What is the reason for that?

MR. DIETERT: According to laboratory results, you can obtain the maximum strength when the water is added before the oil. Some time ago a member of the Association ran a series of tests and at that time he expressed this theory, with which I agree: If the water is added first, it coats the sand grains, then adding the oil, its surface tension would have a tendency to spread the oil around the sand grains. The oil would be pulled toward the joint where two sand grains touch each other. If the water were added after the oil, then the oil would have a chance to go into the pores of the sand. Neither would the oil slip away from the surface of the sand grains so easily and make point contacts where the sand grains come together. In other words, you get a better joint where the water is added first.

In actual practice, quite frequently, you will find the reverse procedure, followed of adding the water after the oil. The difference is quite small but the time may come when we will endeavor to make this saving.

MEMBER: In other words, you mean there is really more oil available when the water is added first?

MR. DIETERT: Yes.

MEMBER: When there are cereal binders in the mix, though, it is usually the other way around.

MR. DIETERT: You are right.

H. J. HLAVKA:² Mr. Dietert, some work was done similar to that shown in your Fig. 7 which does not seem to be comparable in regard to the maximum tensile strengths that you obtain at, say, 450 deg. F. and up. I think even the 400 deg. temperature curve is rather questionable. In regard to the baking time, at three-quarters of an hour I believe is the first check that you took, and the curve has a down slope all the way. You reach no peak. Our findings were that at all baking temperatures there is a peak and then, of course, falling off in tensile strength. Naturally, at the higher baking temperatures the rapidity of decline is greater, as shown in Fig. 7.

MR. DIETERT: I am very glad this point was brought up, for two reasons. First of all, I should have mentioned the type of oil that was used in this investigation. The oil that we used is a linseed base oil containing 62 per cent linseed, about 2 per cent resin, the remainder being a very light mineral oil. The result is that we had a light, fast-baking oil.

² Smith Oil Co., Rockford, Ill.

Secondly, the baking conditions mentioned were most ideal. With the A.F.A. core test oven the cores are baked in a hurry. If we had used a heavier oil of a different composition, I am sure we would have had the condition you explained.

MEMBER: In regard to Fig. 9, would those results be materially affected by the size of the core?

MR. DIETERT: The test does not cover large cores, but from practical experience we find that same condition holds true with cores weighing 300 or 400 lb. We found that cores made from a mixture where the water was on the low side had weak surfaces or low core hardness. Comparing plant practice with this curve, I would say that the Fig. 9 would hold true for heavy cores as well as for light cores.

MEMBER: Mr. Dietert, commenting on that last question, we have made tests with larger cores and we find it takes about four times as long in 4-inch section cores as it does in a 1-inch section core, as far as baking time is concerned, to get the maximum strength.

MEMBER: Mr. Dietert, did you find any difference in the hardness or in the tensile strength if you used a different mixing time than 2 minutes? In your paper, you state, "Operate the mixer for a period of two minutes."

MR. DIETERT: We did with a different type mixer. We found with one type of mixer we would have to mix the sand at least 7 minutes to get maximum strength. With another type, we had to increase the time to 12 minutes. That was with a certain type of paddle mixer. We mixed longer than two minutes. We first mixed the batch 2 minutes after the water was added, then added the oil and mixed it for 4 minutes additional.

MEMBER: The point I am trying to bring out is, can you over-mull that sand and decrease your hardness in strength?

MR. DIETERT: We ran a test up to 30 minutes, however, not with the most efficient mixer available, and we could not reduce the strength of the core sand mix. What would happen if you would take some of the more modern and efficient core sand mixers and mix for 4 minutes, I am not prepared to say. I am prepared to state on fine molding sand you certainly can over-mull. Whether that would hold true for core sand mixed in your particular type of mixers, I could not tell you.

CHAIRMAN HARRINGTON: The point made is very important, namely, that each foundry or core room department, given a certain type of equipment, must establish for that particular type of equipment the correct time of mixing for maximum results.

MEMBER: In some of the smaller foundries, some of the core makers have the practice of washing their boxes out with coal oil to remove any film or coating they use on their boxes. Does the coal oil that stays on the box affect the surface hardness of the core?

MR. DIETERT: I don't think it would make much difference. However, if the box was first coated with kerosene or any distillate and then not blown out, the kerosene would soak into your core. Assume you left a teaspoon of kerosene in the corner of the core box, then that kerosene would get into the core and would weaken the core slightly.

MEMBER: How soon should a given sand mold be poured after the core has been put in, if you expect to have your cores as strong as when you first put them in there?

MR. DIETERT: Immediately—particularly if you use certain types of binders other than oil.

MEMBER: Several years ago, I rammed up a 3-foot square mold and left some cores standing in it on a block. I had baked them all to the same strength. After about $2\frac{1}{2}$ to 3 hours, they started to lose their strength. They lost from 15 to 20 per cent in $2\frac{1}{2}$ to 3 hours. In 5 hours, they lost 25 per cent. They kept decreasing in strength for about 3 days. Then came a Saturday and I didn't try them again until the following Monday. Then they had about 15 per cent of their original strength. The sand in that mold had 7 per cent moisture content. I used nothing but a good linseed oil in these cores. The cores were not blackened or coated in any way.

MR. HLAVKA: Mr. Dietert, one more question in regard to Fig. 9. In making any comparative tests, it seems that it would be advisable to allow all the test cores to stand a certain length of time to gain a comparable tensile strength. Otherwise, if it took about an hour to make up your test specimens, the specimens made up last would be gaining the advantage and the specimens made up first would be losing rapidly according to the curve at the 1-hour period. Frequently it may take an hour to make up all the test specimens. What do you advise or what procedure did you use in allowing the test specimens to stand a certain length of time to make the tensile strengths more comparable in the end?

MR. DIETERT: The procedure we followed was to load one plate and put it right in the oven. The bottom plate of the core test oven consists of 3 segments. One of these segments was taken out of the core oven and was loaded, which required about 7 minutes. So there was some air drying taking place. This point certainly should be considered very carefully in making test specimens.

Report of Steel Division Committee on Methods of Producing Steel for Castings

To Members of the Steel Division,
American Foundrymen's Association:

Your committee has kept in close touch with the published literature referring to steelmaking processes, and submits the following short report dealing with the situation during the year.

The year 1936 has not been remarkable for any discovery or development of a really striking nature, directly connected with steelmaking processes.

There has been a considerable revival of interest in the Perrin process. This process claims, by producing an intimate mixture of slag and metal, to so speed up the reactions occurring between the slag and metal that they occur in a very small proportion of the time normal in the orthodox steelmaking processes. The character of the slag can be varied to control the nature of the reaction desired, and when deoxidation is brought about by this means the claim is made that the oxygen content can be brought so low that the addition of silicon or aluminum produces no non-metallic inclusions.

One of the members of your committee reports an application of this idea which is being tried by the Swedish General Electric Company, and which has been described in the correspondence section of the September, 1936, *Metal Progress*. This firm has developed a two-frequency furnace, in which a low frequency can be superimposed on the high frequency, causing such vigorous stirring that the slag is emulsified. It is understood, however, that the problem of refractories is at present affecting the success of this process.

For members interested the Perrin process referred to has been patented in the United States and abroad, and the principal U. S. patent number is 2,015,691.

An interesting process reported by several of our committee members is one of a duplexing type, described by H. B. Kinnear and H. W. Gillette, in an article published in the December, 1936, issue of *Metals and Alloys*, entitled, "Cupola Hot Metal Duplexing for Electric Steel Foundries."

In this process a cupola is used to melt steel scrap, the resulting iron being afterwards treated with soda ash for the reduction of sulphur, in either a forehearth or in a ladle. The resulting high

NOTE: This report was presented before the Steel Division Session of the 41st Annual Convention, Milwaukee, Wis., May 4, 1937.

carbon molten metal is then treated in an electric furnace and the carbon reduced to the desired point by the usual method of iron ore additions. It is believed that the method offers a possibility of economy in conversion cost, due to the cupola melting coupled with a greater tonnage from the electric furnace and a saving in refractories due to the use of hot metal. The article referred to contains a detailed description, with the results obtained on actual melts carried out by the process, which may be of interest to some of our members.

While on the subject of duplexing, the interesting development referred to by one of our committee members, Major R. A. Bull, at the last A.F.A. Convention, has been carried considerably further during the year, although no detailed descriptions or results obtained are available at the time of writing this report. Should these become available in the interim, it is proposed to ask Major Bull to report upon them separately, afterwards involving his report as part of the present one when published.

In his report for 1935, your chairman gave a number of details of the operation of the Sesci type furnace, which, as you will remember, is a pulverized fuel-fired furnace, of a rotating type, developed in Europe.

During the past year efforts have been made to keep in touch with the progress of this method of producing steel, and recent reports indicate the following situation.

While, apparently, the furnace has maintained the reputation it had developed as a means of producing metal for gray iron castings of a special type, pig iron of controlled analysis, and malleable iron, its development in the steel industry has not been at a rapid rate during the year. The installation, referred to in the previous report at a large railroad plant in England, has continued satisfactorily and for the railroad castings produced in this shop has superseded the open-hearth furnace previously used. Your chairman, however, has not found it possible to obtain cost figures, and, in the absence of any facts to the contrary, it is assumed that the original lining troubles are still experienced.

The promoters of this furnace informed your chairman recently that its use for general steel foundry purposes was not being pushed, principally due to the fact that sulphur pick-up had become a detrimental factor in the cases of those steel foundries producing work to rigid chemical specifications. Efforts are being made to develop a technique of applying a basic lining to the furnace, with

a view to removing this objection, but the results of their experiment are not yet at hand.

While not essentially a matter of steelmaking process, the question of furnace insulation is so closely related that it is believed a few comments on this situation would not be out of place in this report.

In the April, 1936, issue of *Metals and Alloys*, there is a survey of results obtained and the materials used for the insulation of open-hearth furnaces under the name of Edwin F. Cone which is of rather unusual interest. This article consolidates the report of 20 companies on their experience in insulating open-hearth furnaces, giving the extent of insulation, its effect upon furnace life, fuel consumption, etc. It refers, specifically, to the types of insulation used in the different parts of the furnace and represents an excellent analysis of the situation to date on matters of furnace insulation.

The following published articles are suggested by your committee as being of considerable value and as representing modern tendencies:

1. "*The Economical Operation of Induction Furnaces*," by Franz Tolztuter, STEEL, Vol. 64, January 27, 1936.
2. "*The Operation of Large-Size Coreless Induction Furnaces*," by Friederick Badenheuer, STEEL, May 11, 1936.
3. "*Electric Furnace Practice*," by G. R. Walker and E. J. Dabswell, THE FOUNDRY TRADE JOURNAL, April, 1936.
4. "*New Open Hearth Checker*," by M. K. Mellott, THE IRON AGE, March 19, 1936.
5. "*Open Hearth Stainless Steel*," by Sam Tour and T. W. Lippert, THE IRON AGE, September 17, 1936.
6. "*Determining Clean Steel*," THE FOUNDRY TRADE JOURNAL, July 16, 1936.
7. "*The Technical Importance of Iron and Steel Scrap*," by Clyde E. Williams, THE IRON AGE, May 28, 1936.
8. "*Electric Steel*," ANON., METAL PROGRESS, vol. 30, pp. 67-80, Nov. 1936. A pictorial description of electric furnace steel practice at Timken.
9. "*Electric Arc Furnaces Economical for Small Heats*," by A. E. Greene, ELECTRIC WORLD, vol. 106, pp. 44-45, Aug. 15, 1936. Brief description of installation at the Olympic Foundry, Seattle, Wash.
10. "*An Electric Arc Furnace in Paris*," ANON., JOURNAL DUE

- FOUR ELECTRIQUE, vol. 45, pp. 309-11, Sept. 1936. Brief description of a 3-ton Heroult-Stein installation.
11. "The Production of Alloy Steel Castings," Anon., METALLURGIA, vol. 14, pp. 85-88, Aug. 1936. Brief description of Clyde Alloy Steel Company practice. Stobie arc furnaces are used.
 12. "Ford's New Facilities for Casting Alloy Steels," Anon., THE IRON AGE, vol. 137, pp. 22-25, April 30, 1936. Brief descriptive article.
 13. "Top Charged Electric Furnace," FOUNDRY TRADE JOURNAL, vol. 55, p. 124, Aug. 13, 1936. STEEL, vol. 98, pp. 41, 72, Jan. 1936. Brief description of the new Moore Lectromelt top charging mechanism.
 14. "Top Charge Melting Unit Handles Bulky Scrap," Anon., STEEL, vol. 98, pp. 41, 872, Jan. 1936. Description of the top charge Lectromelt furnace.
 15. "More Scrap Can Be Utilized in New Top Charge Electric Furnace," by W. B. Wallis, TRANS. ELECTROCHEMICAL SOC., vol. 68, pp. 43-51, 1935. WASTE TRADE JOURNAL, vol. 48, pp. 4-5, 11, Jan. 1936. A cost comparison shows a 5-ton side charge melted 1181 tons of scrap borings and other materials to produce 1125 tons of steel ingots. Two 5-ton charged furnaces have been installed, each having a monthly capacity of 2000 tons. The top charge type uses less power, electrodes, refractories and labor than side charged type.
 16. "Design and Application of Electric Steel Melting Furnaces, in Particular in Plants for High Quality Steel," by F. Polzgoter, ELEKTROWARME, vol. 6, pp. 38-46, Jan. 1936. Also METALS AND ALLOYS, vol. 7, pp. MA 343, July, 1936. Advantages of melting alloy steels in the electric furnace are discussed. Furnace types are described and operating data are given.
 17. "Repairs to Electric Melting Furnaces," by Walter Lister, METALLURGIA, vol. 14, pp. 21-22, May 1936. Brief discussion of the repair of electric furnace linings, both acid and basic bottoms for the Heroult type furnace are described.

Respectfully submitted,

Committee on Methods for Producing Steel for Castings

F. A. MELMOTH, Chairman	JOHN HOWE HALL
R. A. BULL	ERNEST LANCASHIRE
CHAS. D. DIETRICH	C. E. SIMS

DISCUSSION

Presiding: H. D. PHILLIPS, Supt. Dodge Steel Co., Philadelphia, Pa.

F. A. MELMOTH¹: Major Bull, a member of our committee, has given me, since our report was prepared, the following information which I think might be properly considered as a supplement to the report proper. Quoting from Major Bull's communication:

"The report mentions the development of a 2-frequency furnace, and indicates that this idea originated in Sweden. I am informed on what I believe to be good authority that a furnace in which low frequency was superimposed on high frequency for developing vigorous stirring was built for the Bethlehem Steel Company under a patent owned by the Ajax Electrothermic Corporation before a similar plan was tried out in Sweden. Reliable information received from abroad indicates that the low frequency coils are no longer used on the Swedish furnaces and that those furnaces now are being operated on high frequency alone.

"Dr. G. H. Clamer informs me that he holds a patent for using a combination of low frequency (Ajax-Wyatt) and high frequency (Ajax-Northrup) furnaces; the former being designed for heating, and the latter being designed for stirring the metal. Dr. Clamer further states that he holds a patent issued to him covering the use of the low frequency coreless method simply for stirring a charge of steel that has been made liquid and super heated in another furnace.

"These references to patents are made solely for the proper guidance of persons who may be interested in the apparent novelty and possible utility of certain steel making methods that are adaptable for casting manufacture."

JEROME STRAUSS²: Mr. Melmoth has made reference in his report to the use of the Perrin process. Possibly some of the members here are not familiar with the ideas involved and would relish a few remarks on the subject. There are a whole series of patents covering the interaction of molten metals of all types with suitable slags. The process as applied to steel has been in use in France for more than six years. The principle is employed with basic electric steel with the objective of reducing the normal refining time from about two hours to about 10 minutes for low-carbon steel and 30 minutes on high-carbon steels. This includes all the preparatory operations and the actual refining step. Simultaneously, great regularity of the properties of the steel is obtained.

One patent of major importance, which is the one Mr. Melmoth has referred to in his committee report, concerns the deoxidation process and involves a violent intermixing of a steel melted by any means, in other words any molten bath, with a highly acid slag of very definite composition. The high speed of the reaction is very significant and it seems important to review this in connection with Mr. Melmoth's description of the double frequency furnace. With the Perrin process, a 15-ton melt is put through the entire reaction, including the separation of the slag from the metal, in less than one minute. The process has been extended re-

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cently in France to Bessemer steel; it must be remembered, of course, that over there it is basic Bessemer steel that is made. Applications of the process are in the initial stages in both England and Norway. Some work has been done in this country.

Referring to my earlier comments, it should be realized that the process is essentially a means of obtaining an acid type of steel when melting has been done on any type of bottom that may be available with the equipment and economic conditions involved in any particular plant. It is of interest to note that the oxygen content of steels finished in this manner is of the order of, in the case of 0.30 per cent carbon steels, for example, say 0.003 per cent. And that means that in producing fine-grained steels aluminum additions are employed that are of the order of 0.005 per cent to 0.010 per cent which in turn means one-tenth to two-tenths of one pound per ton, which is extremely small.

A significant advantage, as I mentioned before, is claimed to lie in the reproducibility of the process. In other words, regardless of the state of the metal bath as melted, the ultimate condition, if temperatures of slag and metal are correct, is a particular oxygen content for a particular composition, and this oxygen content is reproducible from melt to melt without any chance of error. The result is the production of a product of extremely constant properties and this has been proven in the French practice during the manufacture of large tonnages of a number of compositions. The process has been studied rather briefly in this country. One basic open hearth campaign of rather short duration has been carried out and arrangements are now being made for its trial in Bessemer and also in electric furnace operation. Just what importance the process will have to steel foundrymen is rather difficult to say at this time. A definite statement can be made as to steel quality but in respect to the economies involved, it is rather difficult to make any statement this early in the experimentation here.

J. M. SAMPSON²: I would like to ask whether or not this particular process, with which I am not familiar,—is anything like the process used in the Homestead Steel Works over 30 years ago, in which we heated up the amount of the iron ore required in the basic open hearth and when that was up to a good red heat, we put in the direct metal from the mixer and we got a very violent reaction. Of course, in a 60-ton open hearth we probably cut that capacity down to approximately 70 per cent of the normal output. In this process, we would drop the carbon as much in a few minutes as was ordinarily possible in an hour or an hour and a half. The reaction was so violent sometimes that some of the slag and metal would boil up and out of the doors. I would like to know if the process described by Mr. Strauss is a revival of this older process.

MR. STRAUSS: This process has no relation to the old Talbot process that you speak of. As you have indicated, the Talbot process was of such character the steel was very often on the plant floor rather than where it should have been.

You have by the Perrin process a deoxidation reaction with metal which has been melted down to some low carbon and metalloid content

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depending upon the ultimate aim, then recondition as far as composition is concerned, and then violently intermixed with an acid type slag of definitely controlled composition, both metal and slag being at definite temperatures. The steel is usually slightly colder than the slag, which is at about 3,000° F. The reaction involved is an emulsification, productive of intimate and instantaneous metal slag contact but there is no violent gas evolution. The reaction is usually accomplished in the ladle; a vigorous action takes place but is not of an uncontrolled nature, and is followed by an immediate separation of slag and metal. The metal is then effectively and uniformly deoxidized.

There is also an application of a similar reaction, by vigorous intermixing, to dephosphorization, but in that case using a basic slag of a definite composition.

CHAIRMAN PHILLIPS: It has been extremely interesting to get Mr. Strauss' explanation of this process. If Mr. Sims were present, he would be very competent to comment on it in its application to steel making for castings, particularly for castings made in green sand molds where we find it necessary to add a certain amount of aluminum, say 0.03 per cent. His work indicates to me that we want to keep a certain amount of iron oxide in our metal before we add that aluminum in order to control the type of inclusions we get and hence get good ductility.

MR. MELMOTH: I have had no actual experience with the Perrin process, but hope to obtain some if in Europe in the near future. I would be interested particularly in facts regarding the fluidity of the finished steel. The extremely low oxide contents claimed if associated with the necessary fluidity, would cause some of us to modify our ideas considerably.

I am surprised to find what a wealth of information Mr. Strauss has been able to accumulate on this process. I believe, however, we should defer judgment of its value to the steel foundry industry until actual practical development has proceeded a good deal further.

MR. STRAUSS: From the customary basic open hearth steel furnace operation, a steel is obtained that contains oxide type inclusions. When those oxide type inclusions are completely removed by an aluminum addition, there is obtained as Sims and Lillequist pointed out in their A.I.M.E. paper, an accumulation of sulphide type inclusions if the sulphur content of the steel is high enough, and these separate around the primary crystals. In the rather numerous samples of steels that have been made by the Perrin process that I have personally examined, I have not had occasion to observe the oxide type or grain-boundary sulphide type of inclusions. The process results in steel definitely of acid character. Oxide inclusions appear to be missing and sulphides are infrequent but there are substituted very small and uniformly dispersed silicate particles. So it is very possible that the foundryman's difficulty of the accumulation of sulphide type inclusions around primary crystals may not occur. Castings have been made in France by this process but I am not sufficiently familiar with them as most of my examinations have been confined to wrought steels.

From the viewpoint of Mr. Melmoth's question, it might be of interest to state that the Perrin reaction is definitely exothermic. And there is a

reversion of silicon. This is over and above any silica that would be included in a silicon determination due to silicate slag particles. There is an increase of silicon content in the same manner as occurs in acid open hearth furnaces, except that in this process the amount of silicon transferred from slag to metal is about twice what is normally obtained in the production of the average acid open hearth heat. It averages around 0.07 or 0.08 silicon of which not more than 0.01 can be accounted for in the form of inclusions.

MR. SAMPSON: Another question. I refer to the so-called silicon pick-up obtainable in the acid process. I know that during the war we were cautioned that if we wanted to finish around say 0.22 or 0.23 per cent silicon, that we should not allow the silicon pick-up to get beyond say 0.16 or 0.17 per cent. In other words, that we definitely added in the form of ferro-silicon say 0.07 per cent or something like that, for final deoxidation. Now if I understand Mr. Strauss correctly, if we get 0.15 per cent silicon in the normal acid open hearth pick-up, we would get twice that amount in this process.

MR. STRAUSS: No, I referred to the normal increase of silicon in acid open hearth operation as distinct from acid electric operation. In the usual open hearth practice, the pick-up is about 0.03 to 0.04 per cent silicon toward the end of the heat; that part of the operation is rather hot. However, the Perrin process introduces, during the slag intermixing, on the average of about 0.07 to 0.08 per cent silicon, so that if the reaction is applied to a steel to which no other silicon is added, it will finish with about 0.08 per cent silicon if initially it is practically silicon free. That amount varies somewhat, however; I have seen some heats with a pick-up as high as 0.13 per cent, but mostly around 0.07 to 0.08 per cent.

MR. SAMPSON: I do not think I have made my point clear. In other words, if when melted, we had 0.05 per cent of silicon, which I think is about average, we would try to get up to 0.15 per cent which would mean about 10 points pick-up. Would this process give a higher silicon pick-up, for instance, than possible in acid open hearth practice?

MR. STRAUSS: This process will add about 0.08 per cent to what is already present at the time the reaction takes place.

The Hardenability of Cast Iron

By D. W. MURPHY¹ and W. P. WOOD,² ANN ARBOR, MICH.

Abstract

The authors present data from five heats to illustrate the use of aluminum additions to molten iron to confer shallow-hardening properties on the iron. The range of additions which produces the most pronounced decrease in hardenability in the base mixture studied appears to be from 0.02 to 0.03 per cent aluminum; larger additions than this result in irons of deep-hardening character. It is further pointed out that the melting practice prior to deoxidizing with aluminum is of great importance in establishing the conditions in the heat that are necessary to obtain the maximum effect on reduction of hardening power from a given aluminum addition. This small addition of aluminum appears to be without effect upon the amount or distribution of graphite but in the as-cast condition irons so treated tend to show larger amounts of very fine pearlite than are found in untreated irons. In general, the chemical analysis does not indicate whether an iron is deep or shallow hardening. While the methods for developing austenitic grain size in this iron are not sufficiently advanced to permit a detailed report, the shallow-hardening irons seem to be characterized by a finer network structure than the deep-hardening irons. Shallow-hardening irons in the as-cast state tend to show a slightly higher deflection rate in the transverse test, a lower tensile strength, and a considerably higher impact strength than do the deep-hardening irons.

1. In a previous paper* the authors presented data on four cupola irons and two induction furnace heats which seemed to indicate that the tensile strength, hardness as-cast, and the ability to harden on quenching from the austenitic state were influenced

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* *Austenitic Grain Size in Cast Iron*, Trans. A.S.M. vol. 24, p. 75, 1936.

NOTE: This paper was presented at the session on Gray Cast Iron at the 41st Annual A.F.A. Convention, Milwaukee, Wis., May 4, 1937.

by the size of the network formed in these irons. For want of a better designation, it was suggested that this network outlined an austenitic grain size which was effective in influencing the as-cast properties by reason of the variation in hardenability which attends variation in austenitic grain size. Attention was called in that paper to the fact that the variation in properties such as the increase in strength, hardness, and hardenability which seemed to be associated with an increase in the size of the network paralleled rather closely the well-known effects of variations in austenitic grain size in steel. In the discussion of this paper, questions were raised with regard to the possible influence of the phosphorus content of these irons on the network structure.

2. The work which forms the basis of this paper was done on four unalloyed gray iron electric furnace heats in which the charge consisted of clean scrap from an all-steel cupola heat made in the University foundry and clean, low-carbon steel punchings. During the heats the carbon was built up by means of furnace additions of graphite. Because of the charge selected, both sulphur and phosphorus were maintained at low values. Several ladles were tapped from each heat and the metal poured into dry sand molds as 1.2 in. bars. The various treatments given these four heats and the chemical analyses of the resulting irons are summarized in Table 1.

3. In the present paper, the authors desire to illustrate further the rather extensive variations in the properties of irons of similar analysis which may arise as a result of certain deoxidation treatments. Aluminum was used as the deoxidizer, although it was realized that many foundrymen regard aluminum additions to cast iron with considerable apprehension. The main reason for its choice was that its use in steel making is extremely common for the purpose of controlling grain size and hardenability, the amount added to the steel being dependent upon the melting practice obtaining in each heat to a considerable extent. The use of aluminum as a deoxidizer in these cast iron heats would offer, then, a means of comparison between the effects in steel and the effects in cast iron.

4. Heats *A* and *B* were intended to study the effects of aluminum additions varying from 0.025 to 0.275 per cent on cast iron. Based on the results obtained in heats *A* and *B*, two additional heats were made in which the aluminum additions varied only from 0.015 to 0.060 per cent. The analyses of Table 1 show that in general the very small additions of aluminum of from

0.015 to about 0.025 per cent affect the amount of combined carbon scarcely at all. Heat *B* is an exception, but this iron had a higher combined carbon than Heats *C* and *D*. However, additions of aluminum of the order of 0.04 to 0.06 per cent show a definite tendency to decrease the amount of combined carbon by about 0.10 per cent and larger amounts of aluminum further decrease the combined carbon. Aside from this, there is little in the analytical data on each heat which would account for variations of properties within the heat.

STRUCTURE OF IRONS

5. The structures exhibited in the various irons are summarized in some detail in Table 1. The graphite distribution in general followed three types, as shown in Figs. 1A, 1C and 2A. The first type, and possibly the most desirable distribution, is random in nature, as illustrated by Figs. 1A and 2A, which are photomicrographs of samples D1 and D5 in the unetched condition. Distribution of this type is rated as good in the table. A second type of distribution was that in which the graphite outlined at least a partial dendritic pattern and is illustrated in Fig. 1C. This particular formation was attributed by Di Giulio and White² to excessive superheating, the amount of superheating required to produce this distribution being in part dependent upon the composition of the iron. Such a distribution as this is rated in the table as fair to poor, depending upon the amount of graphite so distributed and upon the completeness of the dendritic pattern. A third type of structure is illustrated in Fig. 1C. In this structure, fine graphite is associated with either ferrite or pearlite, the graphite flakes being small and fine and giving a rather characteristic lacy appearance to the structure in that region. This type of structure was frequently found associated with the second type as shown in Fig. 1C and at least when it occurs in this manner it does not seem reasonable to rate this distribution more than fair. No attempt was made to determine or rate the effect of this structure when it was found in small amounts since its influence under these circumstances would probably be small.

6. From the results of microscopic examination, listed in Table 1, it appears as though the small addition of aluminum of the order of 0.02 per cent has little or no effect upon the graphite distribution, the characteristics of the untreated metal predomi-

² Di Giulio, A., and White, A. E., *Factors Affecting the Structure and Properties of Gray Cast Iron*, Trans. A.F.A., vol. 43, p. 531 (1935).

nating. With larger additions of aluminum, however, there seems to be a tendency toward the production of undesirable characteristics in the graphite distribution. The irons showing the best graphite distribution are C1, C2, C4, C5, D1, D2, D4, D5, with C6, D6, and D7 slightly less favorable, and B1, B2, B3, B4, C3, C7, and D3 showing the least favorable distribution. Among the irons of good distribution there seems to be scarcely enough difference to cause marked changes in properties.

7. The summary of the etched structures in Table 1 shows some differences in the irons with respect to the fineness of the pearlite, especially in the case of Heats *C* and *D*. The finest pearlite was found in D5, D4, C5, C4, D2, and C2, while B2 showed a finer type than B1 but not so fine as the other samples. All of these samples were treated with aluminum, either in the ladle or the furnace, in the amount of 0.02 to 0.03 per cent. Large additions of aluminum, as a rule, did not produce as much of the fine pearlite as did the lower addition. This difference in fineness of pearlite was the major difference in the matrix structures of the irons, and this is illustrated in Figs. 1B, 1D, 2B, and 2C. Figs. 1B and 1D, which are photomicrographs of D1 and D3, show a medium to fine pearlite and a medium to very fine pearlite, respectively. At 250 diameters most of the lamellae are resolved in these cases. However, in the case of D5, showing a very fine pearlite structure, much of the pearlite is unresolved at 250 diameters (Fig. 2B) and indeed remains so at 1000 diameters (Fig. 2C). These illustrations of etched structures are fairly representative of the entire series, although, of course, some variation was found, as might be expected.

8. In general, the results of the microscopic study showed that some dissimilarity in graphite distribution would account for some variation in properties, particularly in the case of aluminum additions of the order of 0.05 per cent and larger. And in the case of the etched structures, variations in the fineness of pearlite could possibly contribute to variations in properties.

9. The fact that differences in the fineness of pearlite exist in irons of like analysis, other factors being equal, probably arises from differences in rates of transformation from austenite to pearlite; the more rapid the rate the finer the type of crystallization.

10. One other point regarding the structure of the irons remains to be discussed. Attempts have been made to develop the austenitic grain size patterns of these irons, but have met with

only moderate success. To date, the best observations have been made on the hardened samples cut from the center of the hardenability bars described later. Using a nital etch on these samples, fine grained characteristics are exhibited by D5, D6, and C5 and, to a somewhat lesser extent in D4, D2, and C4. Very coarse-grained characteristics are exhibited by D3, C3, C6, C7, B3, A2, A3, and B2, while C2 and D7 are somewhat variable. A1, A4, B1, C1, and D1 are rather coarse, but less so than the irons previously mentioned. With the exception of sample B2, it might be pointed out, however, that all of the irons showing definite fine-grain structure, namely, D5, D6, C5, and to a slightly lesser extent, D4, D2, and C4, also showed lower hardenability than the other irons. At the present moment, it does not seem advisable to attempt any further correlation of austenitic grain size and other properties, inasmuch as most of the methods so far used on these low phosphorus irons have not been altogether satisfactory.

RESULTS OF HARDENABILITY DETERMINATIONS

11. To determine the ability of an iron to harden, a portion of the transverse test bar equal in length to about four times the diameter was heated to 1525° F., held for one hour and quenched in oil. A piece approximately $\frac{1}{2}$ in. in length was next taken from near the center of the quenched bar and ground flat on both sides in preparation for Rockwell hardness readings. Concentric circles were then marked on one flattened face, starting with a circle about $\frac{1}{16}$ in. from the edge. The radii of successive concentric circles were decreased by $\frac{1}{32}$ in. until a distance of $\frac{1}{4}$ in. from the center was reached, after which the radii decreased by $\frac{1}{16}$ in. Except for the circle lying $\frac{1}{16}$ in. from the center, six Rockwell hardness readings were taken on each circle and the results for the several circles averaged. Figs. 4, 5, 6, and 7 show these results on the irons of all four heats in the graphical form in which Rockwell "C" hardness is plotted against distance from the center.

12. The untreated iron of Heat A, shown in Fig. 3, hardens completely as a result of the quenching treatment. A2, which had been treated with 0.046 per cent aluminum in the ladle, also hardened completely, but at a lower level than A1. Higher aluminum additions, in spite of the decrease in combined carbon, produced irons of definitely deep hardening character. Considering these

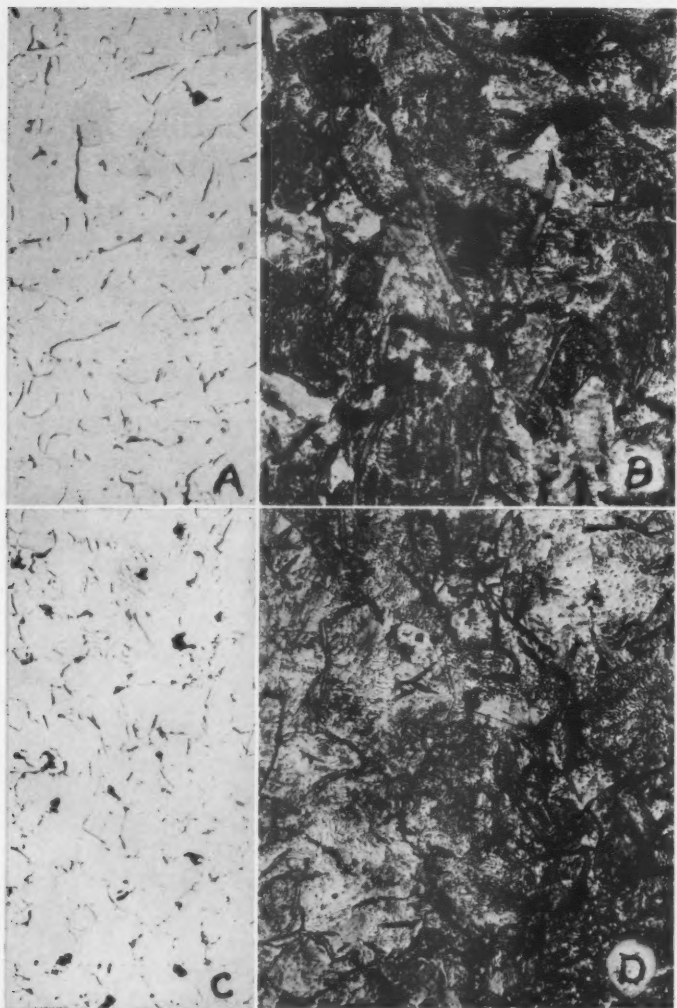


FIG. 1—A—IRON D1 IN AS-CAST CONDITION, UNETCHED, 100X. B—SAME AS A BUT ETCHED WITH 4 PER CENT NITAL, 250X. C—IRON D3 IN AS-CAST CONDITION, UNETCHED, 100X. D—SAME AS C BUT ETCHED WITH 4 PER CENT NITAL, 250X.

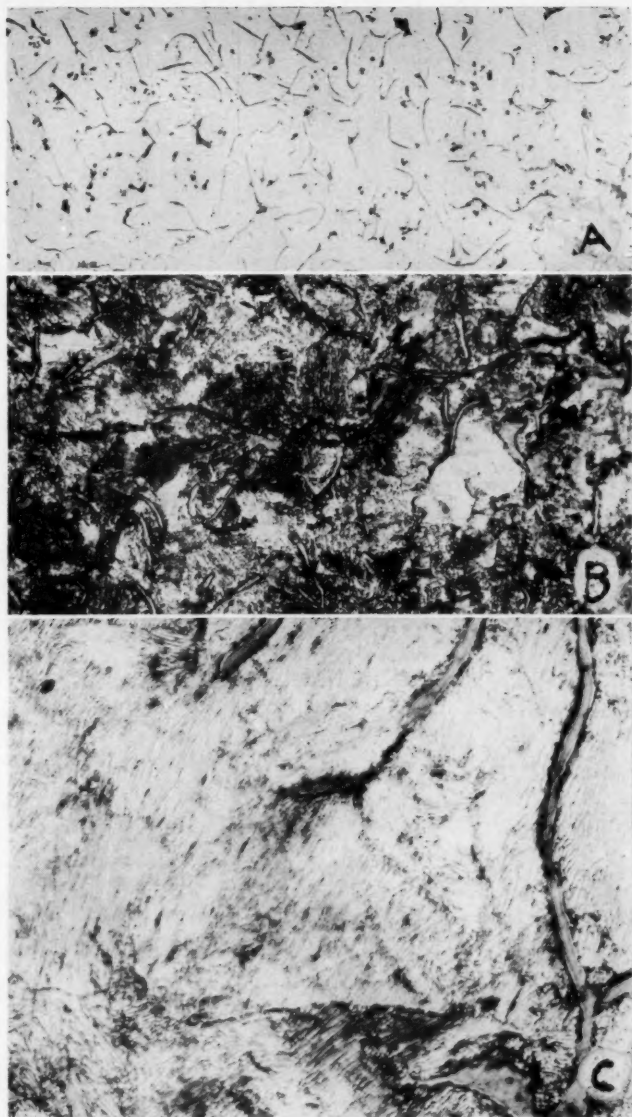


FIG. 2—A—IRON D5 IN AS-CAST CONDITION, UNETCHED, 100X. B—SAME IRON AS A, ETCHED WITH 4 PER CENT NITAL, 250X. C—SAME IRON AS A, ETCHED, 1000X.

Table 1
TREATMENTS, ANALYSES, AND STRUCTURES OF IRONS

Heat No.	Treatment	Tapping Temp. F.	% C.	% Si	Structural Characteristics	Etched
A1	None	2750	1.85	0.94	Partial dendritic pattern at edge—otherwise distribution good. Flakes thin, comparatively short, increase in size toward center, moderate	Pearlite medium to fine. Some excess carbide. No ferrite-fine graphite structure.
A2	.040% A1 in ladle	2750	1.83	0.90	Partial dendritic pattern at edge—otherwise distribution good. Flakes longer than A1 and apparently somewhat more.	Pearlite medium to fine. Little excess carbide. Some ferrite-fine graphite structure.
A3	.10 % A1 in ladle	2750	1.90	0.81	Similar to A2. Flakes heavier than A1 and A2.	Pearlite medium to fine. Very little excess carbide. Slightly more ferrite-fine graphite network.
A4	.205% A1 in ladle	2750	2.03	0.75		
B1	None	2720	1.76	1.02	Partial dendritic pattern. Flakes medium to fine. Distribution fair.	Pearlite medium to fine. Some excess carbide. Some ferrite-fine graphite network.
B2	.028% A1 in ladle	2720	1.85	0.93	Partial dendritic pattern. Flakes similar to B1 in size and distribution.	Pearlite medium to fine on average finer than B1. Some ferrite-fine graphite network. Some excess carbide.
B3	.050% A1 in ladle	2720	1.92	0.84	Partial dendritic pattern more pronounced. Flakes slightly coarser and somewhat more. Distribution not very good.	Pearlite medium to fine. More ferrite-fine graphite network. Some excess carbide.
B4	.275% A1 in ladle	2720	2.00	0.78	Partial dendritic pattern like B1, B2—less pronounced than B1. Flakes coarser and noticeably more. Distribution not very good.	
C1	None	2760	2.23	0.84	Partial dendritic pattern very nearly absent. Flakes rather long, medium thickness—increase in length toward center. Distribution good. Similar to C1 except flakes seem somewhat finer. Distribution good.	Pearlite medium to fine with small amount rather coarse. Some excess carbide. Small amount of ferrite-fine graphite network.
C2	.028% A1 in ladle	2740	2.29	0.82		Pearlite medium to very fine with considerable of latter. Otherwise like C1.
C3	.051% A1 in ladle	2740	2.39	0.73	Partial dendritic pattern but not pronounced. Flakes similar to C1, C2, but some longer and more difference center to outside. Distribution fair.	Pearlite medium to fine with small amounts of very fine and coarse. More ferrite-fine graphite network. Some excess carbide.
C4	.023% A1 in furnace	2760	2.33	0.77	Slight partial dendritic pattern. Flakes finer than C3 and less difference center to outside. Distribution fair to good.	Pearlite medium to fine with some very fine and coarse. Little ferrite-fine graphite network. Some excess carbide.
C5	.042% O ₂ in furnace	2750	2.13	0.95	Similar to C1, C2. Flakes like C1, C2. Distribution good.	Pearlite medium to very fine. Much more of latter than C2. Little ferrite-fine graphite network or excess carbide.
C6	.024% A1 in ladle	2720	2.14	0.93	Slight partial dendritic pattern. Flakes similar to C1, C2, C3. Distribution fair to good.	Pearlite medium to fine with small amounts very fine and coarse. Some ferrite-fine graphite and some excess carbide.

Table 1—Continued

C7	.042% Al in ladle	2740	3.09	2.23	0.86	Partial dendritic pattern more pronounced. Flakes similar to C1, C2, C3, C6. Distribution fair.	Similar to C3 except more ferrite-fine graphite network.
D1	None	2740	3.07	2.36	0.71	1.92 Slight partial dendritic pattern. Flakes similar to C3, C6. Distribution good.	Pearlite medium to fine. Small amount excess ferrite. Little fine graphite-ferrite or pearlite formation.
D2	.019% Al in ladle	2740	3.09	2.30	0.70	Similar to D1. Distribution good.	Similar to D1 but somewhat more very fine pearlite.
D3	.006% Al in ladle	2750	3.10	2.20	0.90	Partial dendritic pattern more pronounced than D1, D2. Flakes somewhat finer than D1, D2. Distribution poor.	Pearlite medium to very fine. Considerable fine-grained ferrite and pearlite network. Small amount excess carbide.
D4	.023% Al in furnace	2760	3.08	2.29	0.79	Similar to D1, D2, with slightly greater variation in flakes from center to outside. Distribution good.	Pearlite mostly fine to very fine. Otherwise similar to D1, D2.
D5	.038% O ₂ in furnace	2750	3.12	2.35	0.77	Similar to D1, D2, D4. Distribution good.	Pearlite mostly fine to very fine. Otherwise similar to D1, D2.
D6	.015% Al in ladle	2750	3.09	2.29	0.80	Partial dendritic pattern more pronounced than D1, D2, D4, D6. Flakes similar to preceding. Distribution fair to good.	Pearlite mostly fine to very fine. Somewhat similar to D3 but not as pronounced.
D7	.041% Al in ladle	2740	3.08	2.16	0.92	Partial dendritic pattern like D4. Flakes rather finer than 4, 5, 6. Distribution fair to good.	Pearlite medium to fine. Otherwise similar to D6.
E1	None	2730	2.97	2.16	0.81	3.00 Partial dendritic pattern. Distribution fair. Some large flakes.	Pearlite medium to very fine. Some fairly coarse. Little carbide. Some fine graphite-pearlite structure.
E2	.019% Al in ladle	2720	2.97	1.91	1.06	Partial dendritic pattern. Distribution good. Some large flakes.	Pearlite medium to very fine; considerable of the very fine with some fairly coarse. Some fine graphite-pearlite structure.
E3	.041% O ₂ in furnace(1)	2700	2.99	2.07	0.92	Suggestion of dendritic pattern. Distribution fair to good. Flakes slightly smaller.	Pearlite medium to fine but more of the coarse type. Little carbide. Some fine graphite-pearlite structure.
E4	.041% O ₂ in furnace	2700	2.97	2.19	0.78	Distribution fairly random, fair to good. Flakes seem some smaller. Partial dendritic pattern but not pronounced.	Pearlite medium to rather coarse; small amount fine. Little carbide. Some fine graphite-pearlite structure.
E5	.017% Al in ladle	2700	2.97	2.08	0.89	Distribution more random than preceding, good. Flakes about same as before—very slight dendritic tendency most pronounced at edge.	Pearlite medium to very fine, small amount, fairly coarse. Little carbide. Some fine graphite-pearlite structure.
E6	.041% O ₂ in furnace	2680	2.97	2.22	0.75	Distribution fairly random with only slight dendritic pattern, good. Flakes seem definitely smaller.	Pearlite medium to fairly coarse as on 4. Little carbide. More fine graphite-pearlite structure.
E7	.018% Al in ladle	2650	2.97	2.11	0.86	Partial dendritic pattern nearly absent. Flakes as in 6. Distribution good.	Pearlite mostly very fine, small amount medium and coarse. Little carbide. Some fine graphite-pearlite structure.
E8	.024% Al in furnace(2)	2690	2.95	2.18	0.77	Similar to E7.	Pearlite medium to rather coarse, small amount fine. Little carbide. Some fine graphite-pearlite structure.
E9	.024% Al in furnace	2660	2.94	2.12	0.82	Partial dendritic pattern becoming more pronounced as in 6, 7, 8. Distribution slightly less favorable.	Pearlite medium to rather coarse, more of finer type. Some graphite-pearlite structure. No graphite-pearlite both present. Little carbide.
E10	.024% Al in furnace	2600	2.87	2.02	0.85	Similar to E8. Flakes fine. Partial dendritic pattern. Distribution fair.	Similar to 9.

(1) Oxygen added as ferric oxide after tapping for E3, E4, E6 tapped 4 min. 5 sec., 6 min. 27 sec., and 10 min. 35 sec. after oxide addition. E3 and E7 tapped 8 min. 50 sec. and 55 sec. after oxide addition.

(2) Aluminum added 14 min. 45 sec. after oxide addition. E8, E9, E10 tapped 15 min. 30 sec., 20 min. 1 sec. and 25 min. 8 sec. after oxide addition.

results, it seemed possible that a pronounced reduction in hardenability might be obtained with additions of aluminum lower than 0.046 per cent.

13. Accordingly, when Heat *B* was made, the additions shown in Table 1 were chosen. It will be seen from Fig. 4 that the addition of 0.028 per cent aluminum represented by curve B2 produced a definitely shallow hardening iron from a metal of definitely deep hardening character. And, as shown in Heat *A*, larger aluminum additions produced irons of deep hardenability.

14. A slightly different distribution of the materials composing the charge was made in the case of Heats *C* and *D* which brought about a higher total carbon and a lower combined carbon. These changes in the charge produced irons, curve C1, Fig. 5, and curve D1, Fig. 6, which hardened completely but to a somewhat lower intensity than was the case of untreated irons in Heats *A* and *B*. But, as found in Heat *B*, the addition of 0.028 per cent and 0.019 per cent aluminum to the ladle during tapping again produced irons of shallow hardening power, curve C2, Fig. 5, and curve D2, Fig. 6, although not quite so shallow hardening as in the case of Heat *B*. A similar size of addition made to the furnace in both heats and given about one minute longer between the time of addition and the time of pouring the bars, showed lower hardening characteristics, curve C4, Fig. 5, and curve D4, Fig. 6, than were found for similar ladle addition. It should be pointed out

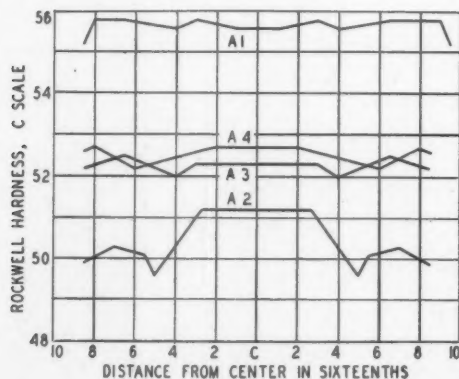


FIG. 3—HARDENABILITY OF SAMPLES FROM HEAT A: A1—NO HEAT TREATMENT; A2—0.046 PER CENT, ALUMINUM IN LADLE; A3—0.100 PER CENT ALUMINUM IN LADLE; A4—0.205 ALUMINUM IN LADLE.

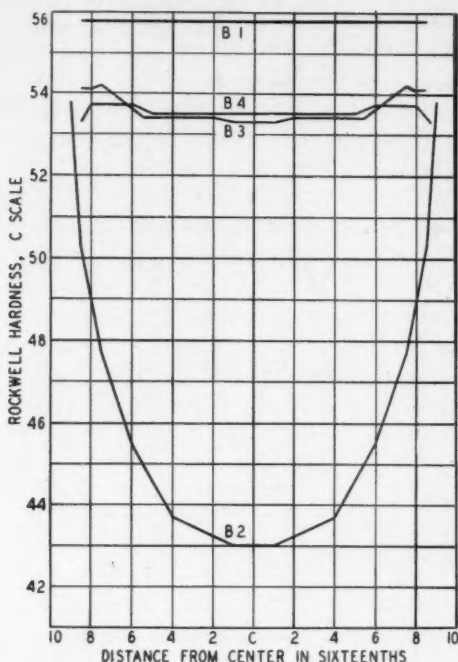


FIG. 4—HARDENABILITY OF SAMPLES FROM HEAT B: B1—NO HEAT TREATMENT; B2—0.029 PER CENT ALUMINUM IN LADLE; B3—0.050 PER CENT ALUMINUM IN LADLE; B4—0.275 PER CENT ALUMINUM IN LADLE.

here that the metal for pouring these bars was held in the ladle for the same length of time as others in this entire series, namely, about 65 to 70 seconds, but the time elapsed between making the furnace addition and tapping was about one minute. Again ladle additions of 0.051 per cent and 0.06 per cent aluminum produced deep hardening irons, curve C3, Fig. 5, and curve D3, Fig. 6; and again at a lower level than was the case in the untreated irons of Heats *C* and *D*.

15. In Heats *C* and *D* an effort was made to see if a short treatment with iron oxide of the metal remaining in the furnace after pouring the bars C4 and D4 would return the iron to a deep hardening condition. Accordingly, after pouring the bars representing the iron treated in the furnace with aluminum, additions of iron oxide were made to Heats *C* and *D* at this point corre-

sponding to 0.042 and 0.038 per cent oxygen, respectively. After holding in the furnace for six minutes, the iron for bars C5 and D5 was tapped into the ladle and again held about one minute prior to pouring the molds. Although the oxide treatment increased the combined carbon, both irons, as shown in curves C5 and D5, Figs. 5 and 6, were shallow hardening.

16. The effect of subsequent ladle additions of aluminum to the iron remaining in the furnace at this point in the two heats

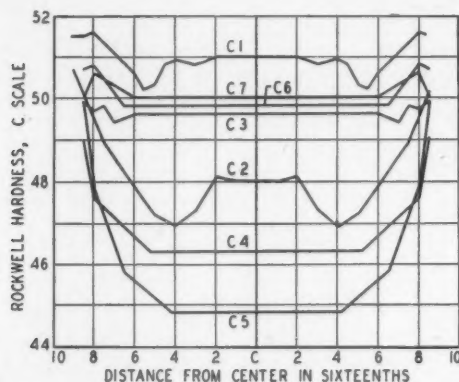


FIG. 5—HARDENABILITY OF SAMPLES FROM HEAT C: C1—No Heat Treatment; C2—0.028 PER CENT ALUMINUM IN LADLE; C3—0.051 PER CENT ALUMINUM IN LADLE; C4—0.024 PER CENT ALUMINUM IN FURNACE; C5—0.042 PER CENT OXYGEN AS FERRIC OXIDE IN FURNACE; C6—0.024 PER CENT ALUMINUM IN LADLE; C7—0.042 PER CENT ALUMINUM IN FURNACE.

showed the same effect as previously noted when the additions were of the order of 0.04 to 0.06 per cent aluminum, namely, that of rendering the irons deep hardening, as shown by curves C7 and D7, Figs. 5 and 6. However, an addition of 0.024 per cent aluminum made the iron in Heat C after the double treatment of aluminum and oxide in the furnace a deep hardening iron, as shown by curve C6, Fig. 5; on the other hand, an addition of 0.015 per cent aluminum made to the iron after a similar furnace treatment in the case of Heat D produced scarcely any change in hardenability in comparison with that of the D5, as shown by curve D6 in Fig. 6.

17. One fact stands out when these curves are considered in conjunction with the analytical results in Table 1. This is that the proportions existing among the various kinds of carbon offer no

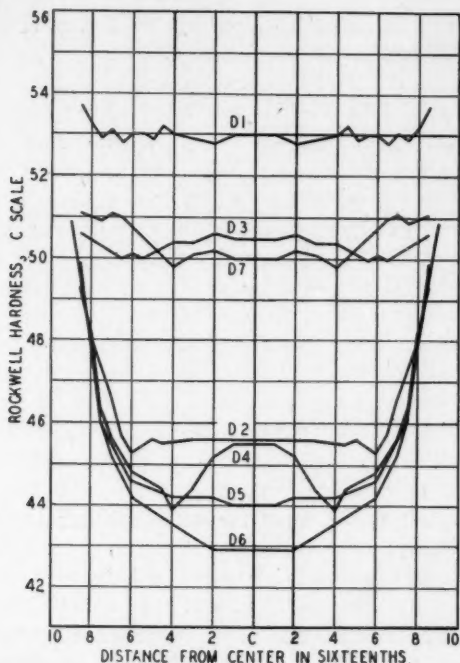


FIG. 6—HARDENABILITY OF SAMPLES FROM HEAT D: D1—NO HEAT TREATMENT; D2—0.019 PER CENT ALUMINUM IN LADLE; D3—0.060 PER CENT ALUMINUM IN LADLE; D4—0.023 PER CENT ALUMINUM IN FURNACE; D5—0.038 PER CENT OXYGEN AS FERRIC OXIDE IN FURNACE; D6—0.015 PER CENT ALUMINUM IN LADLE; D7—0.041 PER CENT ALUMINUM IN LADLE.

clue as to whether or not an iron will possess deep or shallow hardening characteristics, a fact to which J. E. Hurst referred in his paper at the May, 1936 meeting of The A.F.A. The present data show that deoxidation practice can be used very effectively in controlling the hardening characteristics of a given iron and they further indicate the effects of a given amount of deoxidizer, such as aluminum, may depend in a considerable measure upon the various details of melting practice. The necessity for careful study of the deoxidation methods is clearly indicated by the fact that, while shallow hardening irons were produced by additions ranging from 0.02 to 0.03 per cent aluminum, slightly larger additions ranging from 0.04 to 0.06 per cent aluminum produced irons of definitely deep hardening characteristics, notwithstanding

the increased graphitization caused by the higher aluminum addition. The indication of the importance of melting practice is found partly in the deviations in hardening of both the treated and untreated irons in the high and low carbon groups, considering each group separately, and partly in the results obtained by the oxide treatments following the addition of small amounts of aluminum. These latter suggest strongly that there is a relationship between the amount of aluminum added, the condition and degree of oxidation of the iron, and the degree of effect on hardenability of a given size of addition.

18. To check some of these points, a fifth heat, *E*, was made after most of the work for this paper had been completed in which the charge was composed of the same materials as in the preceding heats. Chemical compositions and structures were as detailed in Table 1, but the only physical properties studied were transverse strength and Brinell hardness, as shown in Table 2. The main purpose of this heat was to indicate whether or not the hardenability test would serve to indicate differences in melting and deoxidation practice.

19. Two taps from this heat were made to serve as standards, the first using no ladle addition, and the second about 0.02 per cent aluminum. After the second tap, approximately 0.04 per cent oxygen as ferrie oxide was added to the furnace. Five taps, E3, E4, E5, E6, and E7, were made at intervals extending over a period of about 15 minutes before any further additions were made to the metal in the furnace. To two of these five taps, E5 and E7, aluminum, about 0.02 per cent, was added, the other three being used in the untreated condition. After the fifth tap of this series, an addition of aluminum was made to the metal remaining in the furnace with taps beginning at about one minute after the addition and extending over a ten-minute period, E8, E9, and E10.

20. The various irons obtained in this heat were given the hardenability test previously described, with the results shown in Fig. 7. Irons E2, E5, E7, and E8 will be recognized immediately as having shallow hardening characteristics and of these four E5 and E7 show a decidedly lower order of hardenability than do E2 and E8. Of the deep hardening irons, E4 and E6 show a higher hardenability than do E1, E3, E8, or E9. From these results it is indicated that the hardenability test is quite susceptible to small changes in melting and deoxidation practice and may serve as a useful means of correlation of that type of data. Further

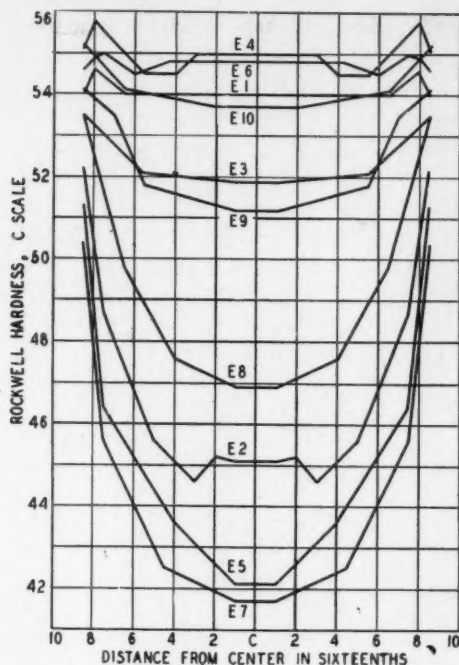


FIG. 7—HARDENABILITY OF SAMPLES FROM HEAT E: E1—NO HEAT TREATMENT; E2—0.019 PER CENT ALUMINUM IN LADLE; E3—TAPPED 4 MIN. AND 5 SEC. AFTER ADDITION OF 0.041 PER CENT OXYGEN AS FERRIC OXIDE TO FURNACE; E4—TAPPED 6 MIN. 27 SEC. AFTER ADDITION OF OXIDE; E5—0.017 PER CENT ALUMINUM IN LADLE. TAPPED 8 MIN. 28 SEC. AFTER ADDITION OF OXIDE; E6—TAPPED 10 MIN. 35 SEC. AFTER ADDITION OF OXIDE; E7—0.018 PER CENT ALUMINUM IN LADLE. TAPPED 12 MIN. 55 SEC. AFTER ADDITION OF OXIDE; E8—0.024 PER CENT ALUMINUM IN FURNACE. TAPPED 15 MIN. 30 SEC. AFTER ADDITION OF OXIDE; E9—TAPPED 20 MIN. 1 SEC. AFTER ADDITION OF OXIDE; E10—TAPPED 25 MIN. 8 SEC. AFTER ADDITION OF OXIDE.

experience on this point is probably necessary before any definite conclusions can be drawn.

21. When the center hardness of the hardened test bars from the various taps is plotted against the time at which the tap is made, the curves of Fig. 8 result. The first result of the addition of oxide to the iron appeared to be a lowering of the intensity of hardening, if not of the actual hardenability. After longer periods of holding, the intensity of hardening recovered rapidly and

eventually exceeded the original material, finally approaching an approximately steady value. The lower curve representing the center hardness of aluminum-treated bars shows a greater reduction in hardening power as a result of the aluminum addition after the oxide treatment has been allowed to yield its maximum effect, a reduction which was considerably greater than was found for a similar addition to the iron prior to the oxide treatment. The last portion of the upper curve after the aluminum addition had been made to the furnace indicates that the influence of aluminum in depressing the hardenability of the iron is one which gradually loses this power. Similar effects are believed to occur in steel production between the first and last ingots poured when fine-grained or shallow hardening steels are being made.

22. It is evident from these data that to obtain the maximum effect in reduction of hardenability by means of a small addition of aluminum, either a certain degree of oxidation or a certain dispersion of oxides is a preliminary requirement. In other words, the melting practice followed in making any particular heat, as well as the amount of aluminum used in deoxidation, is extremely important in determining the subsequent behavior of that iron.

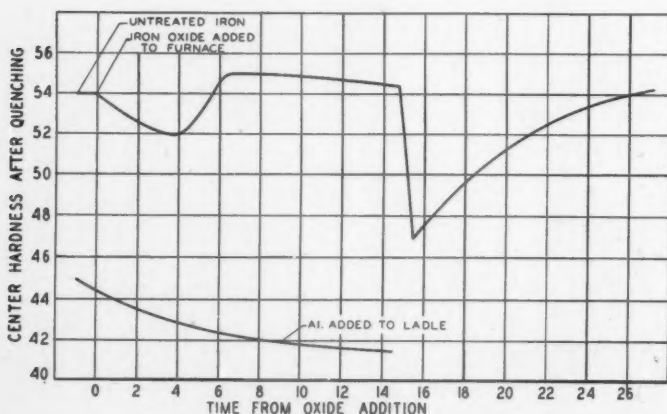


FIG. 8—INFLUENCE OF MELTING TREATMENT ON PRODUCTION OF SHALLOW HARDENING IRONS.

PHYSICAL PROPERTIES

23. Transverse strength, deflection, Brinell hardness, tensile strength, and impact strength were investigated in this series of irons. Transverse strength tests on the *as-cast* bars were made using 18 in. centers, and applying the load at the mid-point between the supports. Deflection measurements were made, using a lever system and an Ames dial, one end of the lever being placed in contact with the under surface of the bar directly beneath the load, while the dial gauge was placed to read the vertical motion of the lever midway between the contact point and the lever pivot. With this arrangement, deflection readings were sensitive to 0.002 in. and usually bars given the same treatment in the ladle were found to check in deflection under a given load to within 0.004 in. The crosshead motion on the test machine in these tests was at a uniform rate and the slowest available on a standard Olsen motor-driven tensile machine. Brinell hardness tests were made on the surface and near the center of a cross section taken from the transverse bar near the fracture.

24. Tensile and impact specimens were machined from the broken halves of the transverse bars. For the tensile specimens, the tentative specifications of the A.S.T.M., A 48-35T for the 1.2 in. bar were used. For the case of impact specimens, the 1.2 in. bars were turned down to a diameter of 1 in. and broken on a 6 in. span in a 240 foot-pound combination Charpy and Izod impact machine. The results of all of these tests are given in Table 2.

Transverse Properties

25. The transverse breaking loads show no consistent trend with variations in deoxidation practice. It is distinctly possible that tests using machined test bars would be much more conclusive, but until more data are available it would be unwise to draw conclusions. The deflections at loads of 500 and 1000 lb., however, do show some correlation, particularly when the varying amounts of combined carbon are taken into consideration. Comparing the shallow hardening irons, B2, C2, C4, D2, D4, with the untreated deep hardening irons B1, C1, and D1, it will be observed that in each heat shallow hardening irons show a greater deflection than do the untreated deep hardening irons, regardless of the comparative values of the combined carbon content. The shallow hardening

Table 2
PROPERTIES OF IRONS

No.	Treatment	Deflection in Inches at Load (lbs.) of:					Trans. Breaking Load, lbs.	Impact Strength Ft. lbs.	Tensile Strength lb. per sq. in.	Brinell		Rockwell "C" Oil Quenched	
		500	1000	1500	2000	2500				Edge	Center	Edge	Center
A	1 ^a	0.0320	0.0640	0.0968	0.1333	0.174	261	36	43750	240	240	56	57
	2	0.046 A1	0.0947	0.0983	0.1490	0.194	201	28	44000	239	242	51	52
	3	10 A1	0.0353	0.0708	0.1103	0.1587	217	2440		226	217	53	53
	4	205 A1	0.0363	0.0730	0.1105		217	2500		225	217	54	53
B	1	None	0.0313	0.0617	0.0935	0.1273	161	2400	42400	244	247	57	57
	2	0.029 A1	0.0373	0.0645	0.0983	0.1355	177	2530	51700	247	247	55	43
	3	0.040 A1	0.0377	0.0647	0.0985	0.1363	186	2430	40100	248	248	55	44
	4	0.0358 A1	0.0358	0.0718	0.1102	0.1547	212	2430		227	226	54	54
C	1	None	0.0355	0.0710	0.1078	0.152	2043	287	50250	239	229	53	52
	2	0.028 A1	0.0390	0.0780	0.1220	0.1747	237	2440	42700	220	216	51	48
	3	0.051 A1	0.0398	0.0792	0.1297	0.1893	272	2460	33300	212	207	51	51
	4	* 0.024 A1	0.0375	0.0752	0.1173	0.1660	220	244	41500	221	216	50	49
	5	† 0.032 O ₂	0.0335	0.0733	0.1060	0.1480	200	2585	32250	240	236	51	45
	6	0.030 A1	0.0340	0.0730	0.1063	0.148	202	2585	32250	240	236	51	45
	7	0.032 A1	0.0365	0.0750	0.1195	0.1740	251	2550	38900	215	212	52	51
D	1	None	0.0333	0.0666	0.1019	0.1430	1917	249	50750	235	231	55	54
	2	0.019 A1	0.0343	0.0686	0.1070	0.1493	204	309	50000	241	234	52	46
	3	06 A1	0.0370	0.0745	0.122	0.158	256	256	35100	215	210	52	51
	4	* 0.023 A1	0.0350	0.070	0.107	0.150	202	321	48000	231	227	53	45
	5	† 0.038 O ₂	0.0340	0.069	0.1048	0.147	198	327	47500	225	227	53	44
	6	0.035 A1	0.0345	0.0692	0.1067	0.149	201	327	47500	225	227	53	44
	7	0.041 A1	0.0380	0.0780	0.120	0.173	243	327	38100	224	209	52	51
E	1	None	0.0340	0.0680	0.107	0.148	195	246		241	235	54	54
	2	0.019 A1	0.0320	0.0660	0.101	0.144	—	194	2490	241	236	52	45
	3	0.041 O	0.0325	0.070	0.105	0.145	193	234	2875	220	231	54	52
	4	0.041 O	0.0330	0.0660	0.103	0.143	191	242	2890	244	234	55	54
	5	0.017 A1	0.0320	0.0660	0.102	0.142	188	260		247	244	52	42
	6	0.012 O	0.0340	0.0680	0.104	0.143	192	243	2885	237	228	55	55
	7	ladle	0.0345	0.0690	0.107	0.149	199	228	2745	247	251	52	42
(b)	8	0.024 A1	0.0330	0.0660	0.102	0.140	189	2800	247	247	234	54	47
	9	* 0.024 A1	0.0345	0.069	0.106	0.151	207	2840	239	229	227	54	51
	10	0.024 A1	0.0350	0.068	0.104	0.148	166	2230(I)	247	237	231	55	53

(I) Flawed.

* Furnace addition.

† Furnace addition.

(a) Furnace addition. E3, E4, E5 tapped 4 min. 5 sec., 6 min. 27 sec., and 10 min. 35 sec. after oxide addition. E5, E7 tapped 8 min. 28 sec. and 12 min. 55 sec. after oxide addition.

(b) Furnace addition made 14 min. 45 sec. after oxide addition. E8, E9, E10 tapped 15 min. 30 sec., 20 min. 1 sec., and 25 min. 8 sec. after oxide additions.

irons, it will be recalled were obtained by adding between 0.02 and 0.03 per cent aluminum to the molten iron as tapped into the ladle or in the furnace. In the case of Heat *E*, there is no consistent difference in transverse strength or deflection between the deep and shallow hardening irons, although, on the average, the deep hardening irons show lower rates of deflection than do the shallow hardening irons. But the changes in condition of this heat were not well reflected in the transverse test, a fact noted in previous tests.

26. It is true that the deep hardening irons, B3, C3, D3, produced with larger additions of aluminum, show on the average a slightly higher deflection than the shallow hardening irons, but it is also evident that the combined carbon contents of these irons is usually about 0.10 per cent lower than for the smaller aluminum additions. This corresponds to an increase in the deflection at 500 lb. of about 0.015 in. Considering the deflection of the deep hardening irons with this correction in mind, it will be observed that most of the increase in the rates of deflection brought about by additions of aluminum up to 0.06 per cent is accomplished by the addition of from 0.02 to 0.03 per cent aluminum. With additions larger than this, the increased deflection due to increased graphitization is in part offset by the increased hardening powers of the irons treated with the higher aluminum addition. It seems reasonably safe to conclude that in general shallow hardening irons will show greater deflections at a given load than deep hardening irons; but the present data do not indicate that this type of data is sufficiently sensitive to show the influences of small changes in deoxidation practice. And further, it should be noted that comparatively large changes in hardenability may be obtained in irons showing comparatively small changes in deflection.

Brinell Hardness Tests

27. The data on the Brinell hardness of the various irons show that the hardenability of the iron can not be judged by the as-cast hardness. Increasing aluminum additions in general decrease the Brinell hardness, although some of the aluminum treated irons, as previously described, are definitely deep hardening. In comparison with the untreated irons of this series, the shallow hardening irons tend to show greater differences between outside and center hardness, but by contributing to increased graphitiza-

tion the larger aluminum additions also show in some cases larger differences between outside and center hardness. The as-cast Brinell hardness, in general, does not appear to promise a correlation with hardening power or with deoxidation practice.

Tensile Properties

28. The tensile test data on the various irons in Table 2 seem to indicate that this test may prove useful in correlation with deoxidation practice, although the values obtained are perhaps more dependent upon graphite content and distribution than seems desirable. It is indicated, however, that the shallow hardening irons, in general, are lower in tensile strength than the deep hardening untreated irons by amounts varying from about 7 to 15 per cent for this particular section size. This seems to confirm an observation previously reported by the authors that shallow hardening irons or irons which show an inherent tendency to fine austenitic grain size also tend to show lower tensile strength than deep hardening or inherently coarse-grained irons.

29. The fact that increased graphitization may also account for decreased tensile strength is illustrated by the deep hardening irons arising from the addition of amounts of aluminum in the range of from 0.04 to 0.06 per cent. These consistently show lower properties than either the deep hardening untreated irons, except for Heat *B*, or the shallow hardening treated irons. Nevertheless, it will be noted from the table that shallow hardening irons will show a tendency toward lower tensile strength in comparison with deep hardening irons of similar nature, which is difficult to explain on the basis of chemical composition or graphite dispersion.

Impact Strength Properties

30. The data on impact strength included in Table 2 indicate that, in general, the truly shallow hardening irons will show higher impact strength than deep hardening irons of nearly the same chemical composition, regardless of whether the deep hardening characteristics are a result of aluminum treatment or not. This test appears to be of a type which will detect variations in deoxidation practice more readily than any of the tests thus far described, except hardenability. It is quite evident that high tensile strength does not imply the highest impact strength. Of the irons

listed in the table, B2, C4, C5, D2, D5, and D6 seems to be more truly shallow hardening than the other similarly treated irons C2 and D4 in that these latter do not show uniform low hardness in the center of the quenched samples. Of those which might be classed as truly shallow hardening, only B2 and C4 have an impact strength much below 40 foot pounds and in the case of B2 its value of 28 foot pounds is well above that of B1, the untreated metal of that heat which showed only 24 foot pounds in the impact test. The general trend exhibited by these truly shallow hardening irons in comparison with the deep hardening irons is that they show a higher impact strength, the difference in some cases amounting to as much as 25 per cent.

GENERAL DISCUSSION OF PHYSICAL PROPERTIES AS AFFECTED BY HARDENABILITY

31. The incompleteness of the present data precludes any attempt to thoroughly correlate physical properties and hardenability. One factor which appears to add to the difficulties is the influence of the condition of the graphite on the physical properties in addition to whatever influence the hardenability may have on these properties. Certainly, however, the conclusion is justified that hardenability in a cast iron may be affected by melting and deoxidation practice in a way which is very similar to that found in steel; and furthermore, within limits, variations in the amounts of combined and graphitic carbon bear no direct relationship to the hardenability. The present data also indicate quite strongly that, in order to obtain consistently a desired effect from the addition of a small amount of aluminum, it will be necessary to control many of the factors which are important to melting practice in the case of steel, but which up to the present time have received but scant attention. One notable example of this is the use of slags to control the degree of oxidation of the metal before the aluminum is added. The ability to control effectively the grain size and hardenability in steel by aluminum or other additions has only been attained as a result of considerable research on the use of slags in conditioning the heat before the addition of such an element as aluminum.

32. The as-cast physical properties seem to have no simple relationship to hardenability. The data of the present paper, as well as that presented in a previous paper, indicate that most of them are influenced to some extent by variations in hardenability

and grain size. There is a strong indication that decreasing section size tends to emphasize the differences arising from variations in hardening power. The reason for this probably lies in the fact that as the section size decreases the cooling rates approach those which might be attained in quenching so that the properties are representative of a heat-treated condition rather than a slowly cooled condition. A study of heat-treated properties of irons of varied hardenability cast in standard test bar sizes should prove valuable as an indication of the variations to be expected from different cooling rates. An investigation of this type has been in progress for some time and will be reported at a later date.

33. The data accumulated thus far tend to support the conclusion that most of the ordinary physical tests are less sensitive to changes in melting and deoxidation practice than is desirable if they are to be used as a means of correlation. Some of these, as, for example, tensile strength and as-cast hardness, would perhaps be reasonably accurate in mirroring changes in melting and deoxidation practice when the section size of test pieces is small, say, of the order of $\frac{1}{4}$ to $\frac{1}{2}$ in.; but as the size of section increases the variations in properties arising from variations in melting and deoxidation practice or from variations in hardenability tend to become less, as well as partly obscured by the operation of other factors, such as increasing graphitization. But in addition to their importance in the application of heat-treated irons, hardenability tests of the type described here are apparently less influenced by such factors as graphite distribution and consequently may serve the better to detect certain fundamental changes in the behavior of the matrix, which, as shown by Heat E, are influenced by both melting and deoxidation practice.

SUMMARY AND CONCLUSIONS

34. It has been shown in the data described in this paper that consistent differences in hardenability of cast irons arise from variations in deoxidation practice. It has also been demonstrated that melting practice, particularly those conditions which may affect either the degree of oxidation or the kind of oxides formed and their dispersion, has a considerable influence on the effect of a given amount of deoxidizer on the behavior of the metal. These changes in melting and deoxidation practice are apparently more readily followed by hardenability tests than by most of the physical properties. There is a suggestion in the results published here,

as well as previously, that some of the physical properties may show more consistent variations with melting and deoxidation practice in sections smaller than the 1.2 in. bars used in this investigation. It is also indicated that a study of the properties of heat-treated irons of varying hardenability characteristics may prove enlightening to our conceptions of the influence of various factors on physical properties. In view of the relative incompleteness of the data so far assembled on this problem, the following conclusions should be regarded as tentative, particularly as they pertain to physical properties:

(1) Wide differences in the hardening power of irons of similar composition and graphite dispersion exist which can not be explained by ordinary chemical analyses or by differences in graphite distribution.

(2) These differences in hardening power are related directly to the deoxidation and to the melting practice.

(3) Aluminum additions of the order of 0.02 to 0.03 per cent produced shallow hardening characteristics in the base irons studied; larger additions of aluminum, however, failed to produce shallow hardening characteristics, although they did produce a slightly lower intensity of hardness in the heat-treated condition.

(4) The resolution of the austenitic grain size has not been as successful as might be desired, but, in general, it seems as though the truly shallow hardening irons show a fine austenitic or inherent grain size in comparison with the deep hardening irons. Further work remains to be done in developing methods of grain size resolution.

(5) There is an indication from the microscopic studies that the fineness of the pearlite in the iron may vary with the hardenability, the shallow hardening irons showing the finest pearlite. It is suggested that the variation in fineness of pearlite is due to variations in the rate of the austenite to pearlite transformation, the shallow hardening irons possessing the higher rates of transformation.

(6) The as-cast transverse properties obtained from the 1.2 inch bars were relatively insensitive to changes in hardenability, although it is indicated that shallow hardening irons show greater rates of deflection than do deep hardening irons.

(7) As previously reported, the tensile strength of as-cast bars decreases in the shallow hardening irons. It is suggested that this property might show greater variation in smaller sections.

(8) Brinell hardness tests on sections from 1.2 in. bars as-cast are relatively insensitive to changes in hardenability.

(9) Shallow hardening irons seem to show a considerably higher as-cast impact strength than do deep hardening irons. This test may prove useful in studying the effects of changes in melting and deoxidation practice.

(10) Generally speaking, the as-cast physical properties of the 1.2 in. bars do not reflect well the changes in hardenability brought about by variations in melting and deoxidation practice. It is suggested that heat treated properties, as well as those of small sections as-cast might be more responsive to these changes.

DISCUSSION

Presiding, DR. JAS. T. MACKENZIE, American Cast Iron Pipe Co., Birmingham, Ala.

DR. A. E. WHITE¹: I do not have anything to add to this paper but we may possibly give some of the past history with regard to it that may be interesting to this group.

Some years ago the director of research of Eastman Kodak, said he did not know just what kind of research to support and, after it was decided to support it, he did not know when to stop. He gave as an example the case of the development of the colored pictures, which he predicts in the next five years will become almost universal.

It seems there were two young men who wanted to start experimenting in that direction and, with a good deal of reluctance, he gave his approval to their starting. After they had been working for three or four years, he was ready to quit, he said he did not feel as though they had made any progress. However, those over him persuaded him to continue and within a year such progress was made that the director now predicts that four years from now there will be practically no black and white pictures taken with our cameras. They will probably be all color pictures, both in the stills and in the movies.

Now, it so happened that Dr. Murphy who has presented this paper, having some spare time on his hands came to us with a request that we give him some very slight financial assistance in the way of providing some materials and supplies and some added assistance. He, out of his own enthusiasm, was ready to contribute his own time toward this particular work. I think we owe a great deal of gratitude to him for the persistence with which he has followed this work and with which he intends to continue it for the next year, and for the rather interesting and, we may say, very valuable results which I believe will be forthcoming to the foundry industry in the next few years through making use of the applications of some of the things that Dr. Murphy and Professor Wood are bringing out.

¹ Director of Engineering Research, University of Michigan, Ann Arbor, Michigan.

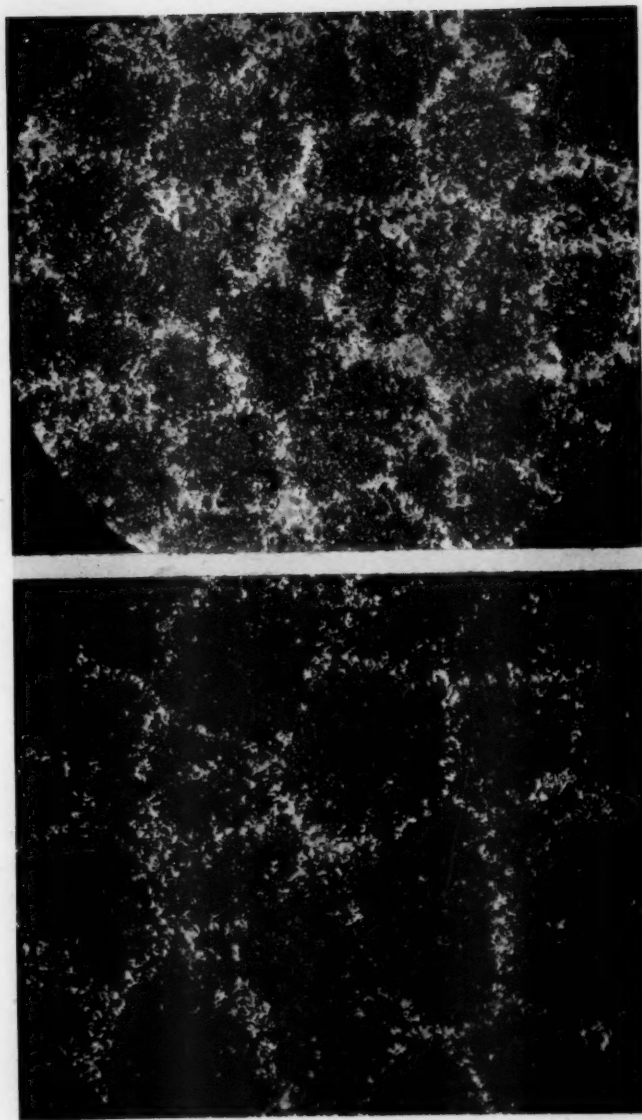


FIG 9—(LEFT) MICROGRAPH OF IRON E-4—NITAL ETCH—20X.

(RIGHT) MICROGRAPH OF IRON E-7—NITAL ETCH—20X.

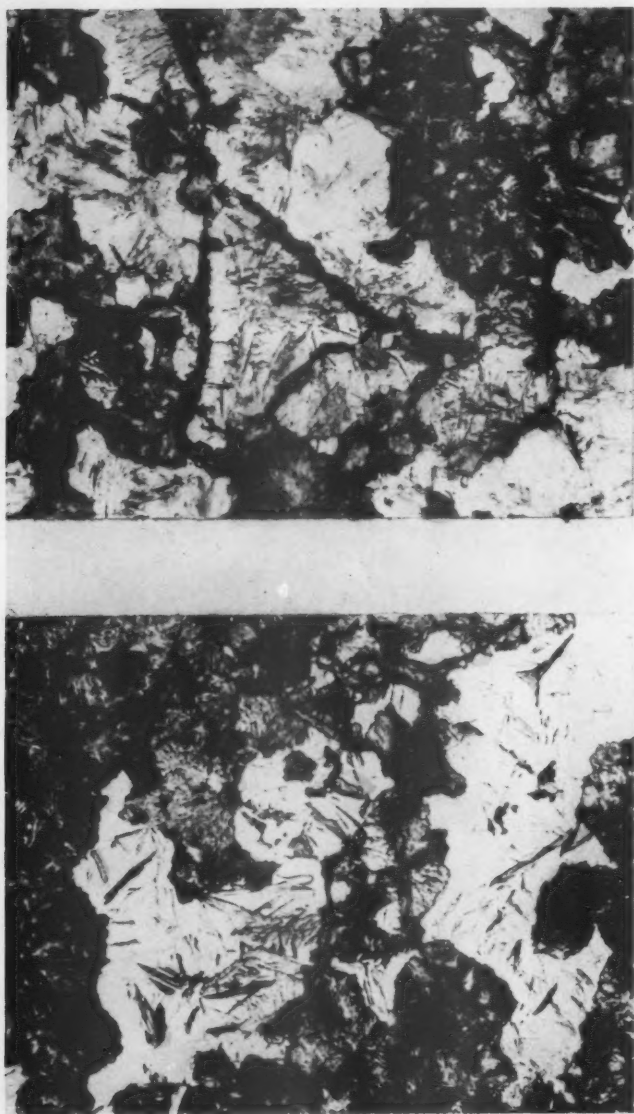


FIG. 10—(LEFT) MICROGRAPH OF IRON E-4—SHOWING PORTION OF MARTENSITIC NETWORK AND TWO GRAINS—NITAL ETCH—1000X.
(RIGHT) MICROGRAPH OF IRON E-7—SHOWING PORTION OF MARTENSITIC NETWORK AND TWO GRAINS—NITAL ETCH—1000X.

H. KENNETH BRIGGS²: I will ask Dr. Murphy to comment briefly on the mechanism of adding his aluminum both to the ladle and to the furnace.

DR. MURPHY: It was added to the ladle while the metal was flowing in. It was simply added through the door of the electric furnace which was used for making the heats.

MR. BRIGGS: Was it added as cold bar stock?

DR. MURPHY: No; we used two different types of aluminum, one consisting of small turnings and the other a comparatively fine mesh material. There is a possibility that some of our previous troubles might have been due to the fact that we were trying to use bar stock. The aluminum was not preheated in either case.

MR. BRIGGS: And no effort was made to plunge it under the surface?

DR. MURPHY: No; we simply threw it in as the metal was flowing into the ladle or threw it in on top of the heat in the furnace and then allowed the furnace to run for a few times in order to secure adequate agitation.

G. P. PHILLIPS³: I would like to suggest to Dr. Murphy that he try to correlate transverse resilience with that of the shallow hardening irons, or that of the shallow hardening irons versus the lesser resilience of the deep hardening irons. You mention the greater deflection of the shallow hardening irons, I believe.

DR. MURPHY: As far as I have been able to go with that, it seems that the resilience of the shallow hardening irons is higher than the resilience of the deep hardening types. Now, that may be somewhat colored by the breaking loads of the two types. If these are fairly close together, as they are quite frequently, then the resilience of the shallow hardening is higher than the resilience of the deep hardening. We are not completely satisfied with some of the data on the breaking loads and other physical properties to do what could be called a really good job of correlation.

MEMBER: As I understand it, Dr. Murphy put the aluminum on the bath as finely powdered material. Does it not burn like a flashlight powder?

DR. MURPHY: We did not use it as a finely powdered material. About 20 mesh was the finest we used. That is not very fine. It does not burn very readily.

D. W. MURPHY and W. P. WOOD (*Written closure*): We would like at this point to include some rather recent data, which we did not have when this paper was prepared, on the austenitic grain size of some of these irons. One type which was used was E-4, which was a very deep hardening iron, and the other was E-7, which was the most shallow hardening iron.

The way in which this test has been developed is as follows: A half cylindrical portion of the bar about three inches long was heated to a temperature somewhere in the region from 1550 to 1700 deg. F., held for

² Metallurgist, Western Foundry Co., Chicago, Ill.

³ Metallurgist, International Harvester Co., Chicago, Ill.

an hour and then quenched, one end in oil, the other end being allowed to cool naturally in air. The longitudinal face was then polished and a section determined between the two types of cooling which showed a good resolution of grain boundaries. A transverse section was then taken at that point and these networks brought out by the ordinary nitric acid or nital etch. Micrographs A and B of Fig. 9 show this network in E-4 and E-7.

Now, it was interesting that that network turned out white, the background black, when we had, as a matter of fact, expected it to be just reversed. By taking some photographs at high magnification, micrographs C and D of Fig. 10, we found that the network in these two cases was martensitic in character.

That seems to indicate again that possibly the rates at which austenite transforms to the alpha forms of iron are quite different in the case of cast iron than they are in steel, probably considerably slower.

Influence of Composition and Section Size on the Strength—Hardness Ratio in Cast Iron

By A. L. BOEGEHOLD*, DETROIT, MICH.

1. The relationship between strength and hardness in any piece of cast iron is determined by the amount and distribution of the various microstructural constituents of cast iron. The amount and arrangement of these constituents is in turn governed by the chemical composition of the iron and the rate and nature of solidification. The latter is affected by rate of heat dissipation and presence of modifying materials which act as nuclei for the beginning of solidification. The nature of these nuclei determine their frequency, therefore the number of centers from which freezing is initiated and thus the overall time for solidification. Let us first examine the various micro-constituents of cast iron as to their composition, hardness, strength and appearance under the microscope.

SILICON ADDED TO FERRITE

2. Fig. 1 shows the effect produced upon the microstructure of ferrite by adding silicon to it. The structure of pure iron is composed of polyhedral grains similar to those of all pure metals. Although the addition of silicon to iron may change the shape of the grain somewhat, no new constituents are visible because the silicon goes into solid solution in the iron. By looking at the structure with a microscope we cannot tell anything about the silicon content. The effect of silicon upon the mechanical properties of iron is to progressively increase the hardness and strength and to decrease the ductility. The amounts are given in Table 1.

CARBON ADDED TO IRON

3. The addition of carbon to iron, however, produces an entirely different effect upon microstructure due to the formation of a compound between iron and carbon. This iron carbide exists in plates or laminations grouped parallel or concentric with each other forming clusters, each having a carbon content of about 0.85 per cent the eutectoid. In low carbon steel these clusters are small and are far exceeded in area by the pure ferrite when viewed un-

* Head, Metallurgical Department, Research Laboratories Section, General Motors Corporation.

NOTE: Paper presented before Gray Iron Session of 41st Annual Convention, Milwaukee, Wis., May 7, 1937.

der the microscope. Fig. 2 shows the microstructure as affected by carbon content. The steel containing 0.25 per cent carbon shows dark patches, each of eutectoid carbon content. Each of these dark patches viewed at high magnification shows alternate layers of ferrite and cementite like the high magnification of pearlite in Fig. 2. With increasing carbon content the dark patches increase in area until the ferrite disappears as in the micrograph in Fig. 2 showing 0.85 per cent carbon steel at 100 diameters.

4. The hardness of pearlite of the type obtained by slow cooling from above the critical temperature is about 200 brinell and the tensile strength about 100,000 lb. per sq. in. The hardness of steels will vary directly as the relative amounts of ferrite and pearlite present as determined by the carbon content, starting at 75 BHN for pure iron and attaining 200 BHN for eutectoid carbon content steel.

Table 1

PROPERTIES OF CONSTITUENTS OF CAST IRON

Constituent	Brinell Hardness No.	Tensile Strength lbs./Sq. In.	Ductility
Ferrite (for comparison)	75 (2)	39,500-42,000 (2)	(61% Elong.) (30.9% Red. A.)
		42,000-48,000 (0-.80 Mn) (1)	28.5-37.5% Elong. 68-75% Red. A (2)
Ferrite—single crystal		36,000 (7) 22,000 lbs./sq. in. (3)	
Silico Ferrite (.82% Si)	88*	55.5% Elong. in 2 in. 45,150 (7)	50% Elong. (7) 91.6% Red. A (7)
Silico Ferrite (2.28% Si)	124*	63,500 (7)	50% Elong. (7) 85% Red. A (7)
Silico Ferrite (3.4% Si)	150*	77,400 (7)	21% Elong. (7) 28.7% Red. A (7)
Iron Carbide (cementite)	680-840 (5)	Very High—Brittle (5)	
Pearlite (silico ferrite plus cementite)	200 (4) 285 (6) up to 450 de- pending upon inter- lamellar distance	125,000 (4) 139,000 (6) 90,000-110,000 (0-.80 Mn) (1)	10% El. 15% R.A. (4) 12% El. 21% R.A. (6)
Graphite	—	—	
Ledeburite (massive cementite plus satu- rated austenite)	680-840		
Steadite (iron phos- phide plus cementite and iron)	High	Brittle	

*Estimated from strength.

(1), (2), (3), (4), (5), (6), (7) reference to sources of data, listed in bibliography at end of paper.

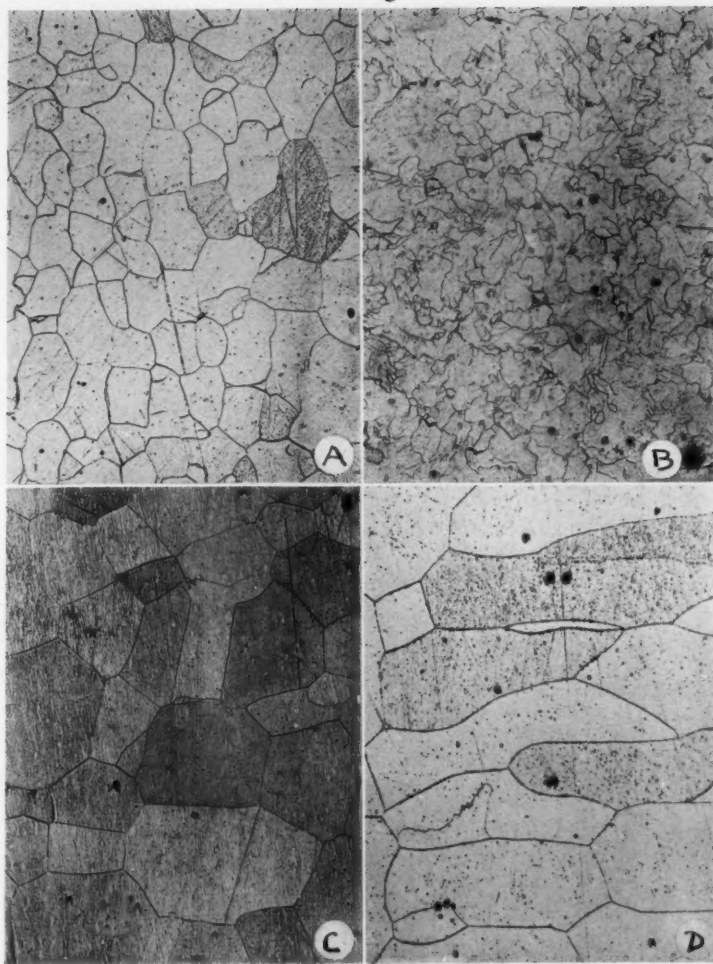


FIG. 1—MICROSTRUCTURE OF IRON AS AFFECTED BY SILICON.

A—Pure Iron, X100

B—Iron—1.06% Silicon, X50

C—Iron—2.63% Silicon, X100

D—Iron—4.4% Silicon, X100

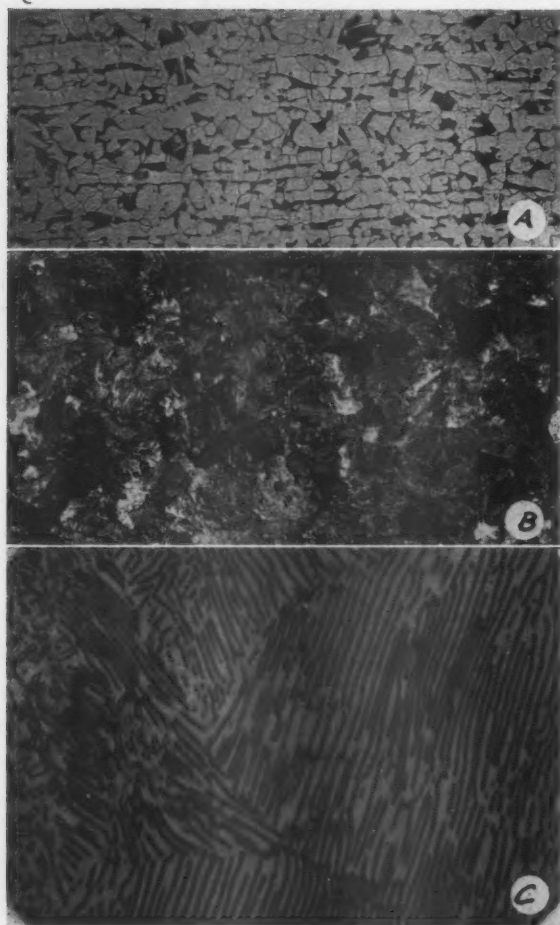


FIG. 2—DETAIL OF PEARLITE IN STEEL.

A—0.25% Carbon Steel, X100
 75,000 lb. per sq. in.
 38% Elong.
 60% Elong.
 128 Brinell

B—0.85% Carbon Steel, X100
 124,700 lb. per sq. in.
 16% Elong.
 15.8% Red. A.
 201 Brinell

C—0.85% Carbon Steel, X2500

5. Fig. 3 shows how the microstructure is affected by addition of carbon to iron up to 4.3 per cent carbon. This unusual structural gradation was found in a piece of low carbon steel which had been left for some time in a furnace for heating bars to forging temperature. A carbon deposit from imperfect fuel combustion formed on the bar and carburized it to the extent shown. Starting at the left of the micrograph we see again the low carbon steel containing about 0.20 per cent carbon. The structure changes toward the right with increasing carbon content until all ferrite is obliterated and then as the carbon content exceeds eutectoid composition, massive cementite appears in increasing amounts until above 1.7 per cent carbon, white patches appear consisting mostly of cementite with small spots of pearlite and proeutectoid cementite. This structure is known as ledeburite and contains 4.3 per cent carbon.

6. Toward the right hand side of the micrograph (Fig. 3) the structure consists principally of this constituent and from its appearance the carbon must be in the neighborhood of 3.50 to 3.75 per cent carbon. This is as high as the carbon content in cast iron but it does not look like cast iron because none of the carbide has decomposed into graphite and ferrite. Why? Because no silicon is present. The hardness of this structure is very high so that it is well nigh unmachinable.

SILICON AND CARBON AND COOLING RATE

7. The effect upon the microstructure of carbon additions to iron containing considerable silicon is much the same as in the case of iron with no silicon so long as the rate of solidification and cooling after freezing is fast enough to prevent the graphitizing action of silicon. For example in Fig. 4 is shown the microstructure in alloys of about 3.40 per cent silicon and varying amounts of carbon cast in $\frac{3}{4}$ in. sections in an iron mold. Here we see the same change in microstructure with increasing carbon content as in Fig. 3 showing iron carbon alloy without silicon. The carbide in excess of eutectoid composition arranges itself in somewhat different fashion but the same general type of structure prevails. However, when solidification and cooling after solidification are slow enough to allow time for the graphitizing action of silicon to become effective, we see massive cementite replaced with graphite.

8. Microstructures of two irons of about the same general composition are shown in Fig. 5. One cast in a $\frac{3}{4}$ in. round sec-



LARGE DARK AREAS
SURROUNDED BY
WHITE EUTECTIC
ARE PRIMARY
AUSTENITE

WHITE AREAS CONTAINING
DARK SPOTS ARE 4.3% CAR-
BON EUTECTICS CONSIST-
ING OF EUTECTIC CEMENTITE
+1.7% CARBON AUSTENITE

1.20 CARBON
PEARLITE
AND
PROEUTECTOID
CEMENTITE

90 CARBON
PEARLITE

50 CARBON
FERRITE AND PEARLITE

20 CARBON
FERRITE AND PEARLITE

FIG. 3—MICROSTRUCTURE OF IRON AS AFFECTED BY CARBON CONTENT.

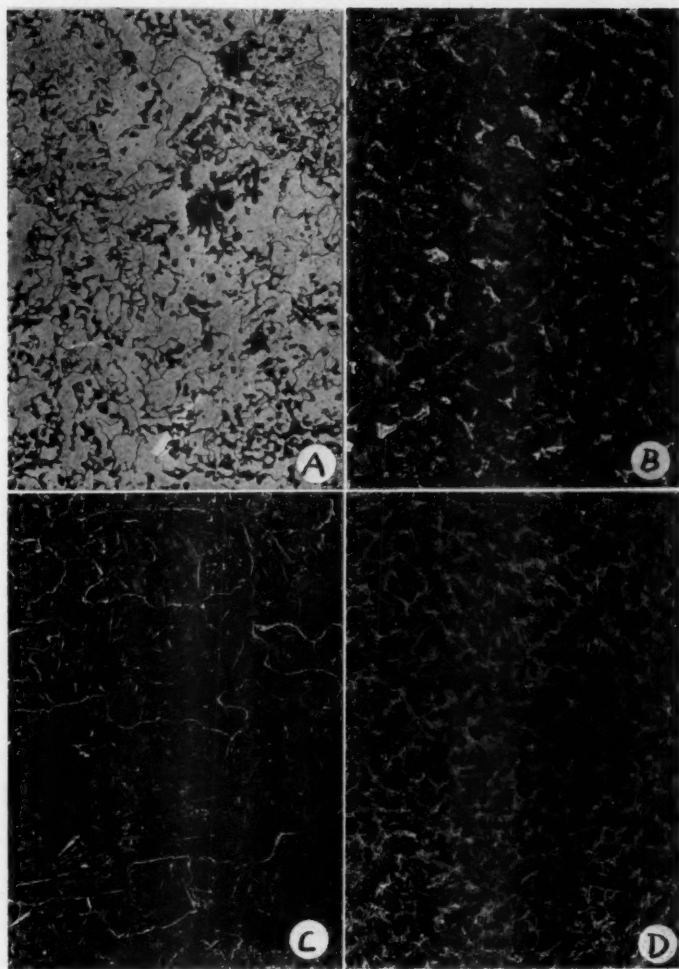


FIG. 4—MICROSTRUCTURE OF IRON AS AFFECTED BY CARBON AND SILICON TOGETHER
 $\frac{3}{4}$ IN. ROUND SECTION CAST IN IRON MOLD.

A—0.31% Carbon 3.46% Silicon
C—1.55% Carbon 3.42% Silicon

B—0.86% Carbon 3.38% Silicon
D—1.78% Carbon 3.58% Silicon

tion in an iron mold shows pearlite and cementite without any graphite while the other sand cast in a $1\frac{1}{4}$ in. square section shows pearlite and graphite and even some ferrite but no cementite. Hence we see the very important part played by cooling rate in the microstructure of cast iron. The diagram (Fig. 6) prepared by Maurer^{*8} showing the limits of composition for the occurrence of various types of microstructure applies only to 1.2 in. diameter castings in a dry sand mold which have one particular cooling rate.

9. For lighter sections having more rapid cooling rates, the boundary lines would be moved to the right indicating that white iron would result with higher carbon and silicon content while for sections heavier than 1.2 in. diameter having slower cooling rates the lines would have to be moved to the left. The diagram as given in Fig. 6 indicates that the composition of the irons shown in Fig. 5 should result in a gray structure which agrees with the structure shown in the $1\frac{1}{4}$ in. square bar but for a $\frac{3}{4}$ in. chill cast iron the boundary line for white iron would have to be moved far to the right to agree with the other structure in Fig. 5. We see, therefore, that the effect that silicon can exert in changing microstructure from that of a similar iron carbon alloy is determined entirely by the time allowed in which to accomplish this change.

10. Whereas iron-carbon alloys with over 1.00 per cent carbon but without silicon always show a mixture of pearlite and massive cementite regardless of how slowly they solidify or cool to room temperature, iron-carbon silicon alloys have structures varying all the way from mixtures of pearlite and cementite to mixtures of graphite and ferrite depending upon the speed of solidification and subsequent cooling. The greatest contrasts in microstructure and hardness may be observed in irons of high carbon and silicon content. At one end of the range with very rapid solidification we have the carbide-pearlite structure which with somewhat slower cooling changes to pearlite with extremely fine graphite and then with still slower cooling rates the graphite flakes progressively increase in size and free ferrite makes its appearance until with very slow cooling the ultimate structure is silico-ferrite and very large graphite flakes.

11. Some of these structures are shown in Fig. 7. In this group are shown cast irons high in carbon and silicon which have been cast in different sized sections. The most obvious effect of

* Superior numbers refer to respective bibliography references at end of this paper.

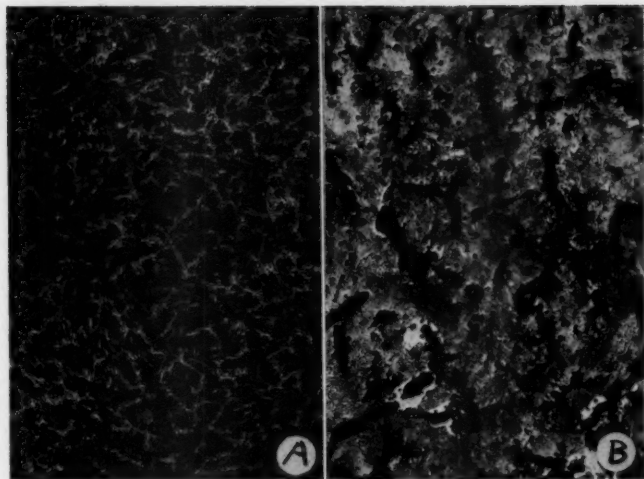


FIG. 5—EFFECT OF SECTION SIZE ON MICROSTRUCTURE.

A—Cast in 3/4 in. Round Section in an Iron Mold 1.78% Carbon 3.53% Silicon

B—Cast in 1-1/4 in. Round Section in Sand 1.81% Carbon 3.06% Silicon

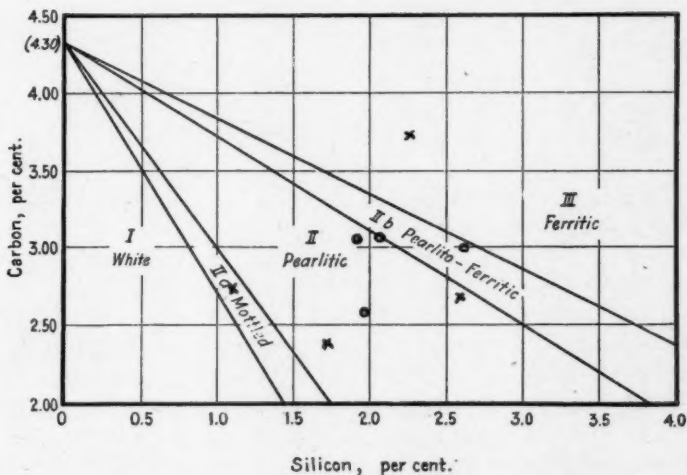


FIG. 6—CONSTITUTIONAL DIAGRAM OF CAST IRON (Maurer).

X—Indicates irons discussed in text having structure not in agreement with the Maurer Diagram.

O—Indicates irons discussed having structures in agreement with the Maurer Diagram.

the variation in cooling rate is the marked difference in size of the graphite flakes. The combination of high silicon and slow cooling in 7 *D* has caused the appearance of some free ferrite. With still slower cooling the graphite flakes would be even larger and the pearlite would disappear and give way to a matrix entirely of ferrite.

12. It will be observed in iron cast against a chill that usually immediately adjacent to the carbide zone, there is a zone of very fine graphite and ferrite and then back of that the normal coarser graphite and pearlite. This seems to indicate that ferrite is produced at a cooling rate more rapid than that resulting in coarser graphite plus pearlite. It should be pointed out here that the solidification rate has first been rapid enough to produce a fine grain structure but that subsequent cooling was not proportional to the solidification rate but proportional to the cooling rate of the remainder of the section which has the effect of annealing the zone which solidified rapidly. Had the rapidly solidified zone containing fine pearlite continued to cool on down through the lower critical temperature at a rate commensurate with its solidification rate the time available for decomposition of cementite would be much less. The annealed permanent mold iron shown in *A* of Fig. 7 is typical of the fine graphite—ferrite structure. Had this not been annealed, the structure would be fine graphite and pearlite. An example of this is shown by Walls¹⁸.

13. Certain methods are now known for modifying the influence of cooling rate upon graphite flake size such as the treatment⁹ with Ti and CO₂ and superheating the iron before casting¹⁰, but there has not been enough done on these processes to make clear whether these modifying agents are effective at any and all cooling rates so our discussion will be limited to a recognition of these methods.

14. When we compare our data as to composition and microstructure with the Maurer diagram, it becomes obvious that there are many exceptions to his results so that the Maurer diagram must be interpreted as applying not only to one particular cooling rate but also to one base composition of iron (as regards phosphorus, sulphur and manganese) and to one particular method of melting because we recognize a number of factors besides carbon and silicon content and cooling rate which determine the tendency for or against carbide formation. These other factors

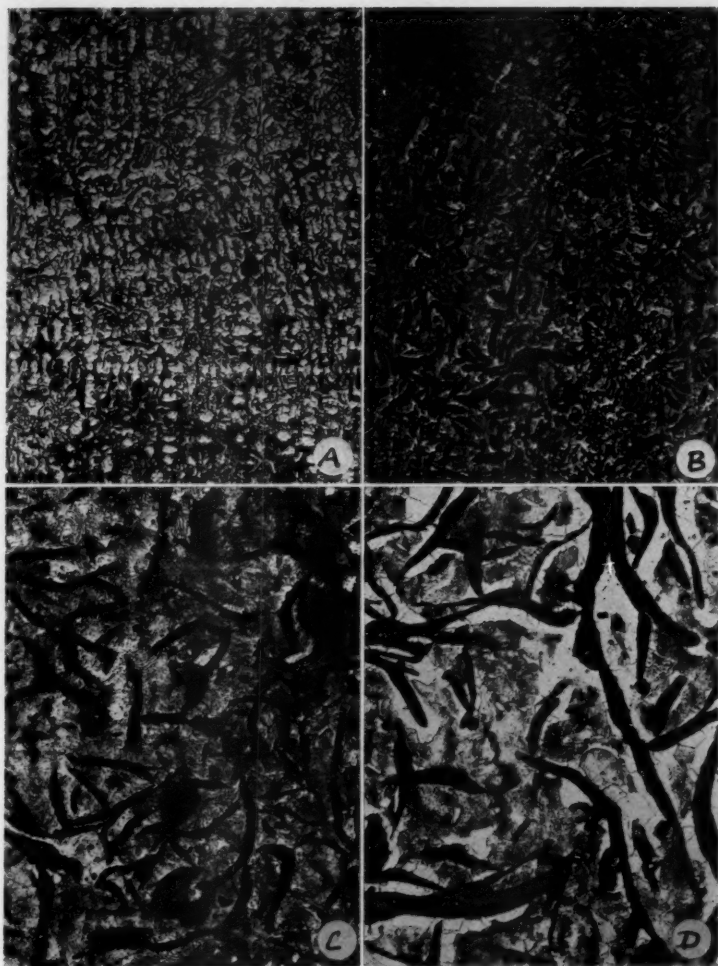


FIG. 7—EFFECT OF COOLING RATE ON SIZE OF GRAPHITE FLAKES.

A—Permanent Mold Casting (Annealed),
X100 3.50% Carbon 2.75% Silicon
B—Piston Skirt, X100
3.33% Carbon 0.80% Manganese
1.93% Silicon 166 Brinell

C—Flywheel Casting, X100
3.33% Carbon 0.64% Manganese
2.19% Silicon 163 Brinell
D—Fly Wheel Casting
3.56% Carbon 0.65% Manganese
2.90% Silicon 126-143 Brinell

include sulphur content, manganese content, oxidation or reduction tendency of the gases in contact with the molten iron, degree of super heat¹⁰, hydrogen content¹¹, and use of ladle additions of graphitizers.

15. As an illustration of why the Maurer diagram cannot be used quantitatively, the microstructure of four irons varying in silicon content and cast in $1\frac{1}{4}$ in. square bars are shown in Fig. 8. The first having a composition commonly used for making malleable iron is shown in the hard condition before annealing. It contains 2.75 per cent carbon and 1.15 per cent silicon. According to the Maurer diagram this should have a mottled structure but it is not mottled but entirely white. This would indicate that the Maurer data were obtained on heavier sections or else by using a melting process conducive to formation of gray fracture.

16. The structure shown in *A* Fig. 8 is of an iron melted by a method conducive to obtaining white fracture and this composition will show white in sections up to 2 in. round. The second example in *B* Fig. 8 is an iron containing 2.36 per cent carbon and 1.72 per cent silicon composition shown in the Maurer diagram to be gray. According to the microstructure of this iron it shows a mottled fracture and again indicates a smaller section size or different melting method than used by Maurer. The next example (*C*, Fig. 8) containing 2.59 per cent carbon and 1.99 per cent silicon shows a gray structure and agrees with the Maurer diagram being right in the middle of the gray zone. The fourth sample (*D*, Fig. 8) contains 2.76 per cent carbon and 2.60 per cent silicon and from its composition should be in the gray zone of the Maurer diagram but its microstructure shows free ferrite and it actually falls in the pearlito-ferritic zone indicating that the cooling rate was slower than the samples used by Maurer to determine his diagram. We can only conclude that the lack of agreement with the diagram was caused by factors other than cooling rate.

17. The hardness of the four irons shown in Fig. 8 is a reflection of the microstructure. The white iron being the hardest due to the plentiful amount of ledeburite and massive cementite. Theoretically the structure of this iron should consist of pearlite, proeutectoid cementite and ledeburite (the structure of the eutectic). The presence of the massive cementite might be explained by assuming that due to supercooling, the formation of hypoeutectic structure progressed beyond equilibrium with the result that the remaining liquid was hypereutectic so that primary cementite had

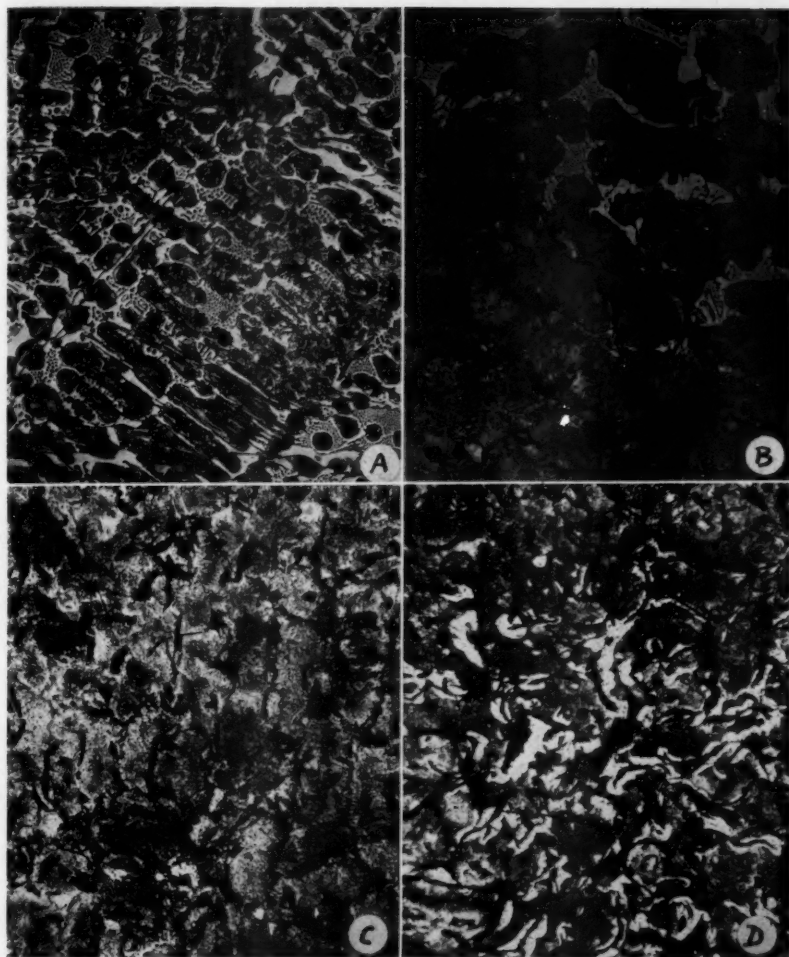


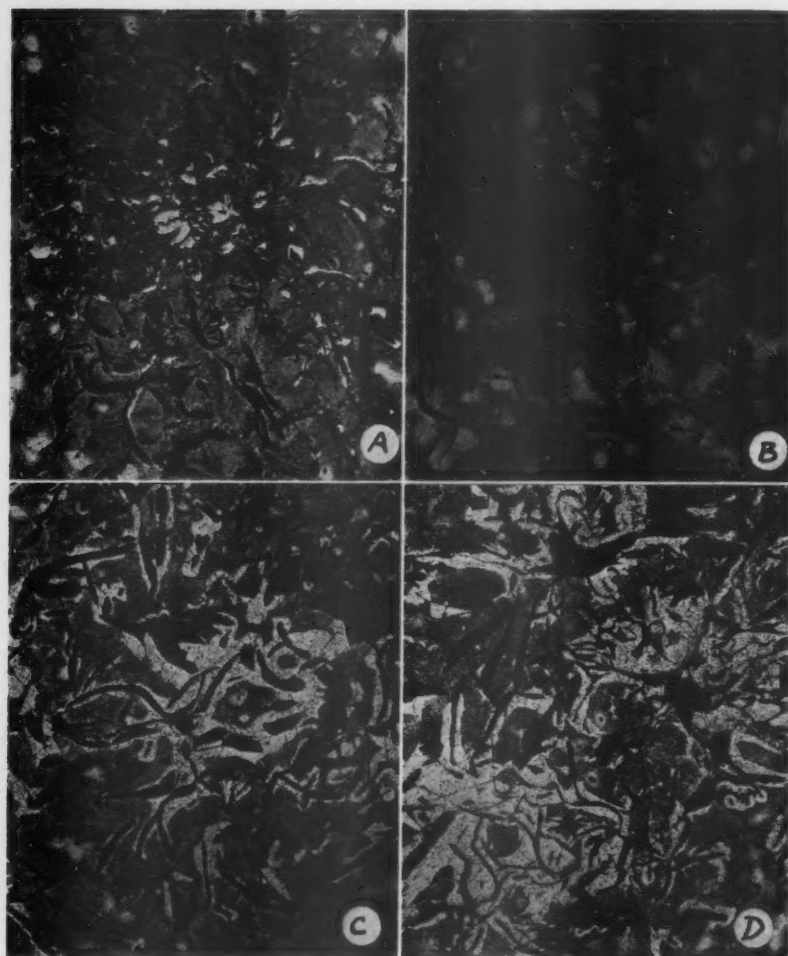
FIG. 8—MICROSTRUCTURE OF IRON AS AFFECTED BY CARBON AND SILICON TOGETHER
— $1\frac{1}{4}$ IN. SQUARE SECTION.

A—2.75 Carbon, 1.15% Silicon, 646-691 Brinell

B—2.36% Carbon, 1.72% Silicon, 285 Brinell

C—2.59% Carbon, 1.99% Silicon, 256 Brinell

D—2.76% Carbon, 2.60% Silicon, 223 Brinell

FIG. 9— $1\frac{1}{4}$ IN. SQUARE SECTION.

A—3.08 Carbon, 2.08% Silicon, 221 Brinell
C—3.00% Carbon, 2.63% Silicon, 176 Brinell

B—3.65% Carbon, 1.93% Silicon, 208 Brinell
D—3.67% Carbon, 2.25% Silicon, 145 Brinell

to form to bring the liquid back to eutectic composition which then froze as ledeburite—characterized by the cell structure.

18. The hardness of the second iron is also influenced by the presence of ledeburite. The third sample at 256 brinell is an approximate indication of the hardness of silico pearlite. Two per

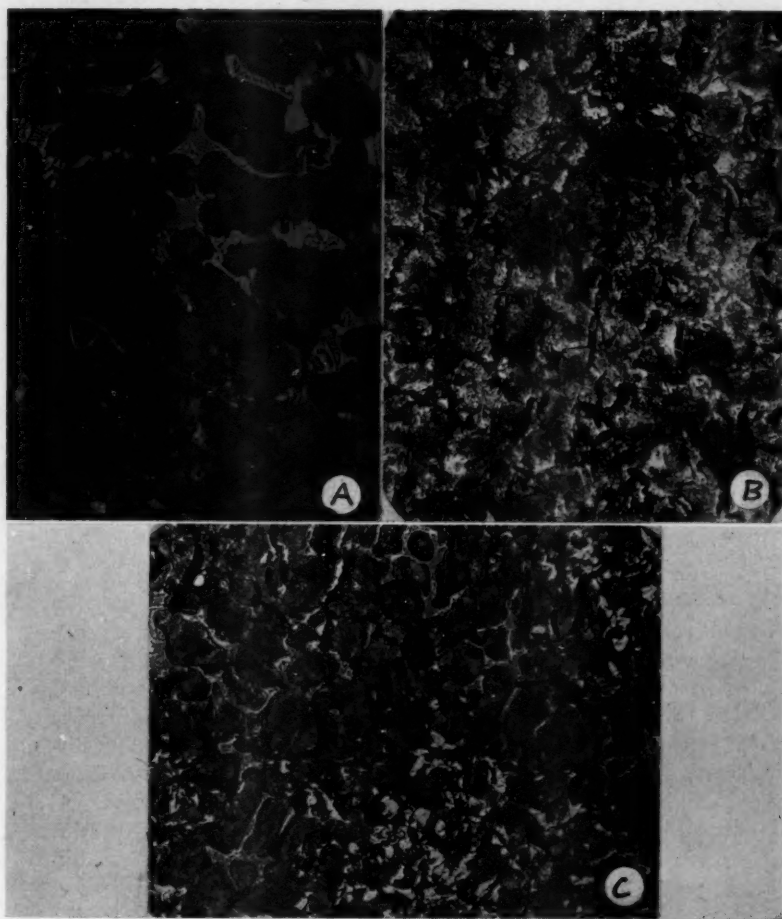


FIG. 10—LEDEBURITE AND STEADITE—1 1/4 IN. SQUARE SECTION.

A—2.36% Carbon	1.72% Silicon	B—2.59% Carbon	1.99% Silicon
0.036% Phosphorus	235 Brinell	0.96% Phosphorus	255 Brinell
C—2.82% Carbon	2.00% Silicon		
0.96% Phosphorus	251 Brinell		

cent silicon increases the hardness of iron about 50 points of brinell hardness. Therefore, since the hardness of silicon free pearlite is 200 BHN, 2 per cent silicon pearlite should be about 250 BHN. This may vary considerably depending upon the distance between cementite lamellae in the pearlite. In this case the actual hardness of the pearlite itself is probably somewhat higher than 256 BHN because the presence of graphite flakes result in a lower observed hardness. Due to the presence of ferrite and larger graphite flakes in the fourth sample, the hardness drops to 223 BHN.

19. In Fig. 9 we have three more irons (*A*, *B*, *C*) of somewhat higher carbon content and enough silicon to render them all gray in the $1\frac{1}{4}$ in. section. All three of these structures agree with the Maurer diagram. Indeed *A*, the one with 3.08 per cent carbon and 2.08 per cent silicon which shows only a small amount of ferrite, falls right on the edge of Maurer's pearlito-ferritic zone as it should. The decreased brinell hardness in these irons is due to the increased amount of graphite flakes and in the third sample to the presence of free ferrite. A fourth micrograph (*D*) in Fig. 9 shows the effect of still higher carbon upon structure and hardness. The combination of 3.67 per cent carbon and 2.25 per cent silicon should, according to Maurer, produce a ferrite structure. The microstructure of a $1\frac{1}{4}$ in. square bar, however, shows considerable pearlite. The low hardness of 145 BHN is caused by the large amount of ferrite and the increased amount of graphite.

STEADITE

20. The one other principal micro constituent is steadite which is an iron phosphide cementite and iron ternary eutectic which somewhat resembles ledeburite in appearance. It is hard and brittle but unlike ledeburite it is present regardless of how slow the phosphorus containing cast iron solidifies and cools. Whereas ledeburite, which is iron carbide, breaks down and disappears when cooled slowly, steadite does not break down even upon prolonged annealing. Fig. 10 shows three cast irons, one, *A*, with ledeburite present in a very low phosphorus iron, one, *B*, with neither ledeburite nor steadite also in a low phosphorus iron but enough higher in silicon to prevent retention of the ledeburite and one, *C*, of similar carbon and silicon content but with steadite resulting from the presence of 0.96 per cent phosphorus. The similarity between these two white constituents is apparent. Indeed if the chemical composition is not known, it is usually neces-

sary to resort to heat tinting or etching with neutral sodium picrate as proposed by Matweieff to determine which of these two constituents is present.

EFFECT ON TENSILE STRENGTH

21. Now having reviewed the hardness and strength of the various constituents which appear in varying quantities in cast iron depending upon composition and cooling rate, and how these varying quantities affect the hardness of the cast iron, it will be interesting to examine how the tensile strength is affected. As a means of approaching this question, the hardness and strength have been plotted of a considerable number of cast irons which have been described in the literature.

22. In Fig. 11 are plotted 25 cast irons reported by McKenzie¹², and shown in Table 2, covering a wide range of compositions and melting methods but all cast in 1.2 in. round ASTM, Type B test bars. Disregarding iron X which is austenitic, iron N which is of unusual composition and made from all pig iron, and iron D containing 1.99 per cent phosphorus it appears that most of the points fall fairly close to a straight line.

23. In Fig. 12 are plotted 16 different irons collected from

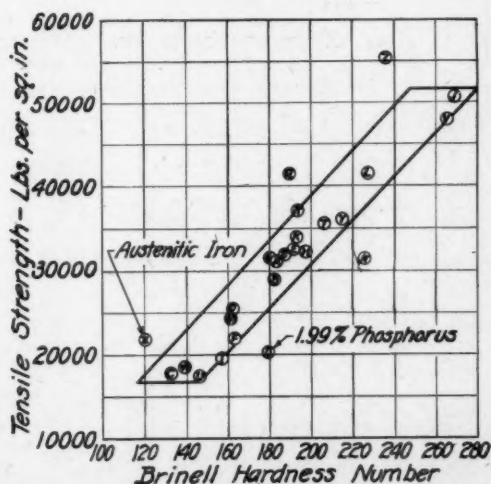


FIG. 11—BRINELL HARDNESS AND TENSILE STRENGTH DATA OF MACKENZIE¹² ON 1.2 IN. DIA. BARS (A.S.T.M.).

Table 2
CASTING DATA AND CHEMICAL ANALYSIS (MacKenzie¹²)

Iron	Furnace	Casting Data				Average Chemical Analysis, per cent*																				
		Tapping Temperature, deg. Cent.	Pouring Temperature, deg. Cent.	Freezing Point, deg. Cent.	Steel, per cent	Pig iron, per cent	Cast Iron Scrap	Mix: 100 per cent minus	Total Carbon	Graphite	Combined Carbon, by difference	Combined Carbon, by color	Silicon	Phosphorus	Manganese	Sulfur, gravimetric	Sulfur, evolved as H ₂ S	Nickel	Chromium	Molybdenum	Titanium	Vanadium	Arsenic	Copper	Tin	
A.	Cupola	1425	1285	1140	10	70			3.49	2.72	0.77	0.87	1.67	0.74	0.54	0.074	0.064	0.00	0.01	0.00	0.00	0.07	0.02	0.06	0.10	0.01
B.	Cupola	1472	1420	1137	12	67			3.53	2.69	0.84	0.76	1.67	0.68	0.56	0.063	0.063	0.00	0.00	0.00	0.00	0.06	0.01	0.07	0.06	0.01
C.	Cupola	1483	1352	1158	10	80			3.95	2.09	0.86	0.76	2.86	1.97	0.62	0.060	0.062	0.01	0.00	0.00	0.00	0.04	0.00	0.03	0.32	0.01
D.	Cupola	1499	1331	1105	13	67			3.25	2.06	0.86	0.71	2.69	1.96	0.53	0.050	0.050	0.03	0.00	0.00	0.00	0.06	0.00	0.05	0.02	0.02
E.	Cupola	1465	1322	1174	4	75			3.61	2.43	0.88	0.68	2.18	1.63	0.44	0.066	0.060	0.00	0.00	0.00	0.00	0.08	0.01	0.07	0.02	0.01
F.	Cupola	1428	1279	1153	10	35			3.49	2.78	0.71	0.65	2.06	0.75	0.52	0.062	0.060	0.00	0.00	0.00	0.00	0.08	0.01	0.08	0.02	0.02
G.	Cupola	1560	1312	1152	20	35			3.39	2.75	0.64	0.52	2.50	0.43	0.74	0.078	0.072	1.17	0.65	0.00	0.00	0.05	0.03	0.01	0.02	0.03
H.	Cupola	1444	1302	1175	10	53			3.41	2.85	0.56	0.57	2.44	0.63	0.57	0.070	0.068	0.01	0.00	0.00	0.00	0.16	0.03	0.01	0.04	0.03
I.	Cupola	1454	1264	1139	0	53			3.41	2.85	0.56	0.57	2.44	0.63	0.57	0.070	0.068	0.01	0.00	0.00	0.00	0.16	0.03	0.01	0.04	0.03
J.	Cupola	1494	1322	1214	85				2.61	1.73	0.86	0.83	2.38	0.06	0.77	0.053	0.053	0.01	0.00	0.00	0.00	0.02	0.00	0.01	0.05	0.01
K.	Are Furnace	1658	1367	1173	20	0			3.14	2.30	0.84	0.83	2.30	0.16	0.79	0.080	0.080	0.25	0.00	0.00	0.00	0.02	0.00	0.01	0.06	0.12
L.	Are Furnace	1649	1364	1181	20	0			3.06	2.62	0.83	0.83	2.50	0.11	0.79	0.080	0.080	0.25	0.00	0.00	0.00	0.04	0.00	0.01	0.02	0.04
M.	Cupola	1572	1369	1172	13	41			3.43	2.75	0.68	0.59	2.35	0.02	1.01	0.035	0.035	1.59	1.55	0.00	0.00	0.05	0.01	0.02	0.04	0.01
N.	Are Furnace	1560	1351	1172	23	0			2.88	2.25	0.83	0.68	1.99	0.43	0.51	0.068	0.062	0.01	0.01	0.00	0.00	0.04	0.00	0.01	0.03	0.01
O.	Cupola	1475	1272	1172	40	60			3.24	2.41	0.83	0.77	1.63	0.42	0.56	0.084	0.079	0.05	0.01	0.00	0.00	0.04	0.00	0.01	0.03	0.01
P.	Reckling Electric Furnace	1572	1369	1172	13	41			3.43	2.75	0.68	0.59	2.35	0.02	1.01	0.035	0.035	1.59	1.55	0.00	0.00	0.04	0.00	0.01	0.03	0.01
Q.	Are Furnace	1560	1351	1172	23	0			2.88	2.25	0.83	0.68	1.99	0.43	0.51	0.068	0.062	0.01	0.01	0.00	0.00	0.04	0.00	0.01	0.03	0.01
R.	Reckling Electric Furnace	1572	1369	1172	13	41			3.43	2.75	0.68	0.59	2.35	0.02	1.01	0.035	0.035	1.59	1.55	0.00	0.00	0.04	0.00	0.01	0.03	0.01
S.	Cupola	1475	1272	1172	40	60			3.24	2.41	0.83	0.77	1.63	0.42	0.56	0.084	0.079	0.05	0.01	0.00	0.00	0.04	0.00	0.01	0.03	0.01
T.	Cupola	1450	1306	1180	0	2			3.49	2.16	1.33	1.48	3.31	0.31	0.82	0.132	0.111	0.00	0.01	0.00	0.00	0.05	0.01	0.01	0.05	0.00
U.	Are Furnace	1652	1360	1164	12	88			3.52	2.50	0.81	0.79	2.20	0.04	0.74	0.042	0.048	0.01	0.01	0.00	0.00	0.03	0.00	0.03	0.34	0.00
V.	Cupola	1457	1354	1218	37	63			3.70	2.60	0.80	0.76	1.47	0.12	0.73	0.083	0.078	0.01	0.01	0.00	0.00	0.03	0.00	0.01	0.12	0.01
W.	Cupola	1513	1356	1145	0	100			3.27	2.22	0.85	0.77	1.87	0.40	0.63	0.070	0.070	0.01	0.00	0.00	0.00	0.04	0.01	0.01	0.21	0.00
X.	Are Furnace	1535	1412	1145	0	100			3.08	2.32	0.76	0.40	2.07	0.04	1.21	0.047	0.040	16.29	1.89	0.00	0.00	0.04	0.01	0.01	0.21	0.00
Y.	Rotary Coal Fired	1333	1266	1142	12	50			3.27	2.22	0.85	0.77	1.87	0.40	0.63	0.070	0.070	0.01	0.00	0.00	0.00	0.04	0.01	0.02	0.12	0.00
Z.	Are Furnace	1526	1448	1170	68	32			2.79	1.94	0.85	0.77	2.44	0.03	0.50	0.060	0.056	0.36	0.09	0.00	0.00	0.02	0.01	0.06	0.36	0.01

* Figures found to contain less than 0.01 per cent.

*All specimens were examined for tungsten and were found to contain less than 0.01 per cent.

two papers, one by Bolton¹³ and the other by Moore and Lyon¹⁴. The plot of these points show a trend somewhat similar to that in Fig. 11. Three irons having abnormally low silicon, 1.10, 1.10 and 1.13 per cent, respectively, for ordinary cast iron are somewhat outside the grouping of the remainder in the group.

24. In Fig. 13 are plotted some values reported by Rother and Mazurie¹⁵ and some by Dierker¹⁶. The hardness values for irons reported by Rother and Mazurie were taken as an average for the center 0.8 in. of each of the cast bars ranging from 1 in. to 3 in. in diameter. In these results there is considerable spread

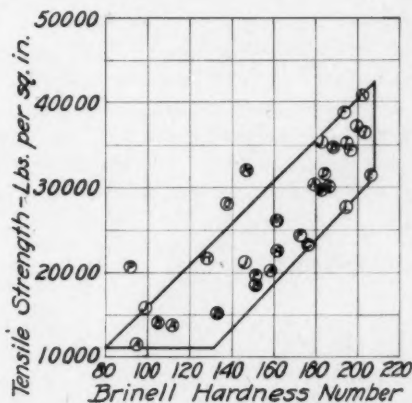


FIG. 12—BRINELL HARDNESS AND TENSILE STRENGTH DATA OF MOORE & LYON¹⁴ AND OF BOLTON¹³ ON SECTIONS FROM $\frac{1}{2}$ TO 4 IN. DIA.

Symbol	T.C. %	Si %	Mn %	P %	S %	Steel %
A	3.52	2.17	0.60	0.32	0.086	5
B	2.50	1.71	0.48	0.36	0.087	10
C	3.54	1.81	0.56	0.38	0.137	0
D	3.57	1.36	0.56	0.26	0.111	20
E	3.51	1.24	0.60	0.29	0.114	15
F	3.24	1.68	0.46	0.33	0.083	20
G	3.39	1.58	0.62	0.34	0.140	10
H	3.35	1.54	0.42	0.54	0.170	15
I	3.42	1.35	0.56	0.29	0.136	20
J	3.16	2.40	0.57	0.27	0.047	8
K	3.16	1.35	0.49	0.37	0.116	25
L	3.16	1.17	0.56	0.32	0.148	25
M	3.56	1.42	0.32	0.75	0.065	Centrifugally sand cast pipe
N	3.44	1.10	0.62	0.51	0.063	Cylinder 18 x 12 x 1 in. wall
O	3.35	1.10	0.60	0.46	0.096	Cylinder 18 x 12 x 3½ in. wall
P	3.30	1.13	0.57	0.40	0.103	25-ton casting

Bars A to L, inclusive, were tests on $\frac{1}{4}$ in., $\frac{1}{2}$ in., 1 in., 1.2 in., 2 in. dia. section, except Bar H, which was 4 in. dia. section—Reported by Bolton¹³.

Bars M, N, O and P were tests reported by Moore and Lyons¹⁴.

in tensile strength for irons of equal hardness. It will be noted that the high carbon content irons are those that have the lowest strength—hardness ratio. The highest strength—hardness ratio are those with low total carbon and especially those cast in heavy sections with low total carbon so that there are a minimum of graphite flakes and carbides to weaken the iron.

25. We cannot expect to always attain the same strength—hardness ratio in thin sections as in heavy sections because it becomes necessary to modify the carbon and silicon content to obtain freedom from hard carbide spots in the light sections and to obtain fluidity to run light sections. The increased amount of graphite flakes is bound to reduce the strength even though the hardness remains the same.

26. If high strength is the most desired property then the best way to obtain it in a light section is to keep the carbon down and raise the silicon. In other words, the objective in any size section for obtaining the maximum strength for any hardness is to adjust the composition so there is a minimum of free carbon with an absence of free carbides, or free ferrite. It may be said

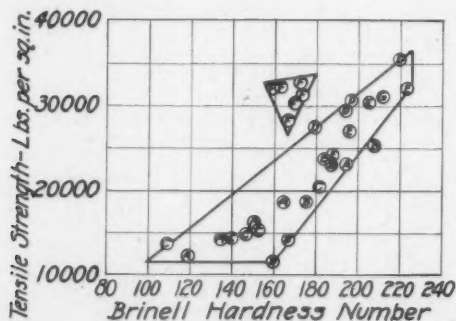


FIG. 13—BRINELL HARDNESS AND TENSILE STRENGTH DATA OF ROTHER & MAZURIE¹⁵ ON 1 TO 3 IN. SECTIONS AND OF DIERKER¹⁶ ON 4 IN. SECTIONS.

Symbol	T.C. %	Si %	Mn %	P %	S %	Steel
A	3.35	2.15	0.65	0.472	0.07	0
B	3.53	1.70	0.85	0.442	0.11	15
C	3.52	2.10	0.60	0.345	0.10	0
D	3.29	1.10	0.95	0.115	0.065	25
E	3.40	1.20	0.90	0.310	0.11	25
F	3.00	1.74	0.54	.114	.036	0—4 in. square
G	3.18	1.83	0.62	.136	.038	0—1.2 in. round

Bars A, B, C, D and E were irons reported by Rother and Masurie¹⁵.

Bars F and G were irons reported by Dierker¹⁶.

that this is always the objective to strive for and is the consideration which determines what composition is most suitable.

27. It has become the custom to refer to the composition which attains this desirable result as a "balanced composition." The melting procedure should be such also to insure a distribution of those graphite flakes present in such a way as to interfere as little as possible with the continuity of the pearlitic structure. There are a number of methods known for controlling graphite flake distribution. One method is to melt a white iron mixture and graphitize by ladle additions. Even when late additions of silicon are made after melting down a gray iron the graphite distribution may be affected sufficiently to have an appreciable influence on the tensile strength.

28. The information¹⁷ in Table 3 shows the physical properties of five irons of almost identical composition prepared in an

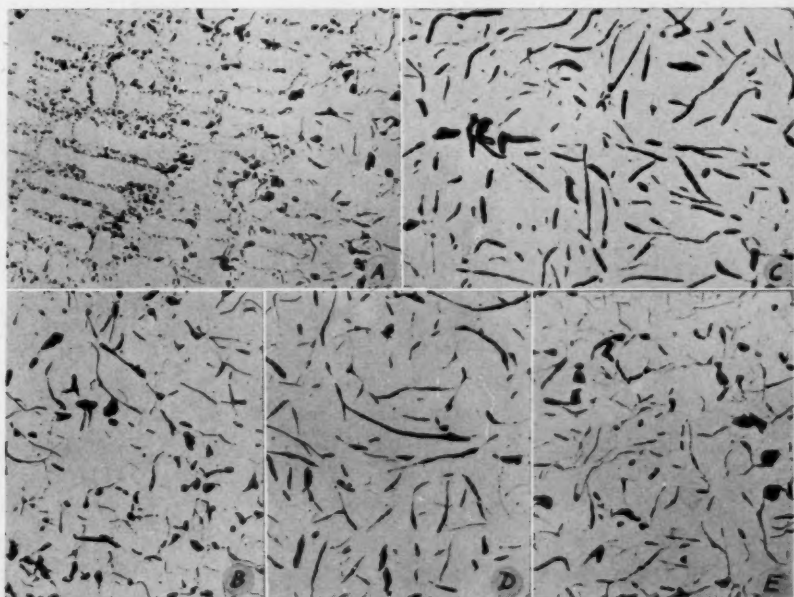


FIG. 14

- | | |
|----------------------------------|----------------------------------|
| A—No late Silicon Addition | B—Late Addition of .58% Silicon |
| C—Late Addition of 1.15% Silicon | D—Late Addition of 1.57% Silicon |
| E—Late Addition of 2.13% Silicon | |

induction furnace from steel, graphitic carbon and ferro alloys in which varying proportions of the total silicon content were added after melting down the charge. Care was taken to obtain all other conditions constant. Baked sand molds were used to produce ASTM type B bars 1.2 in. dia. Molten iron temperatures obtained were 2750 to 2775° F. and pouring temperature was within 2650 to 2675° F.

29. The graphite distribution of these five cast irons is shown

Table 3

PHYSICAL PROPERTIES OF FIVE IRONS OF ALMOST IDENTICAL COMPOSITION

Heat No.	Silicon in Charge %	Silicon added 5 min. before Pouring %	Tensile Strength Sq. In. Lbs.	Brinell Hardness No.	Transverse Breaking Load Lb.	Defl. In.	Chemical Analysis			
							T.C.	C.C.	Mn	Si
1	2.17	—	35,650	217	2266	0.187	3.08	0.58	0.88	2.17
			38,650		2332	0.194				
2	1.50	0.58	42,000	217	2420	0.233	3.10	0.61	0.90	2.08
			43,100		2530	0.250				
3	1.00	1.15	47,600	212	2840	0.314	3.04	0.63	0.89	2.15
			47,500		2895	0.335				
4	0.50	1.57	48,200	212	2990	0.350	3.05	0.67	0.89	2.07
			48,600		2860	0.320				
5	—	2.13	39,400	207	2442	0.245	3.09	0.64	0.88	2.13
			39,550		2510	0.250				

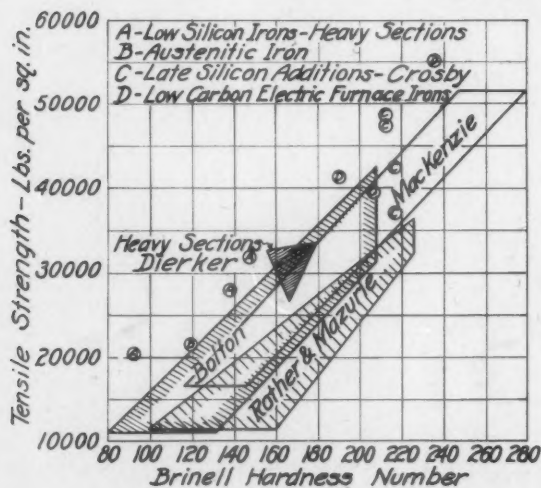


FIG. 15—SUMMARY OF FIGURES 11, 12 AND 13.

in micrographs of Fig. 14. The hardness tensile strength plot of these five irons imposed in Fig. 15 on the outlines for the groups already discussed, range from the lower strength limit to the upper limit at 215 brinell hardness of the group of irons taken from McKenzie¹² showing that graphite distribution alone without change of graphitic carbon content may account for most of the variation encountered in strength—hardness ratio. As graphitic carbon diminishes strength less and less either by change of shape or by decrease in amount, the strength of the iron approaches as a limit, about 120,000 lb. per sq. in.; as long as the pearlite is of the type produced by cooling at rates usually associated with the cooling of castings in the mold. This figure represents the approximate strength of eutectoid pearlite strengthened by silicon.

30. If a composition used for any size section is out of balance on account of too high carbon, too high silicon or because of any other influence that causes more and larger graphite flakes than necessary, the strength-hardness ratio will be decreased. It is obvious in Fig. 15 that many of the compositions represented were not properly balanced for the section size they were cast in. It will be noted that the highest strength-hardness ratios were

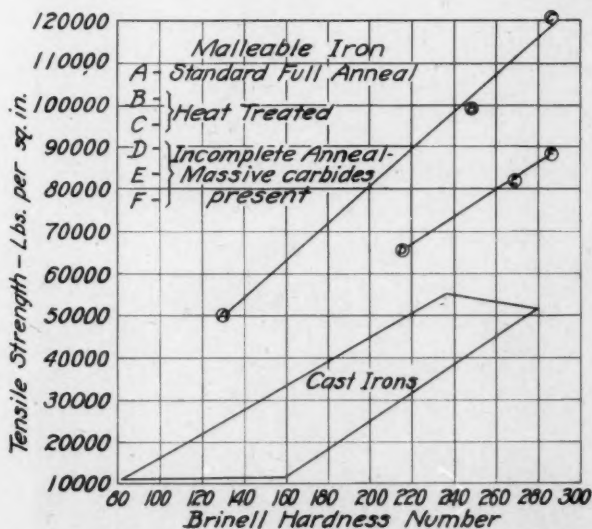


FIG. 16—EFFECT OF FREE CARBIDE AND OF GRAPHITE FORM ON STRENGTH-HARDNESS RATIO.

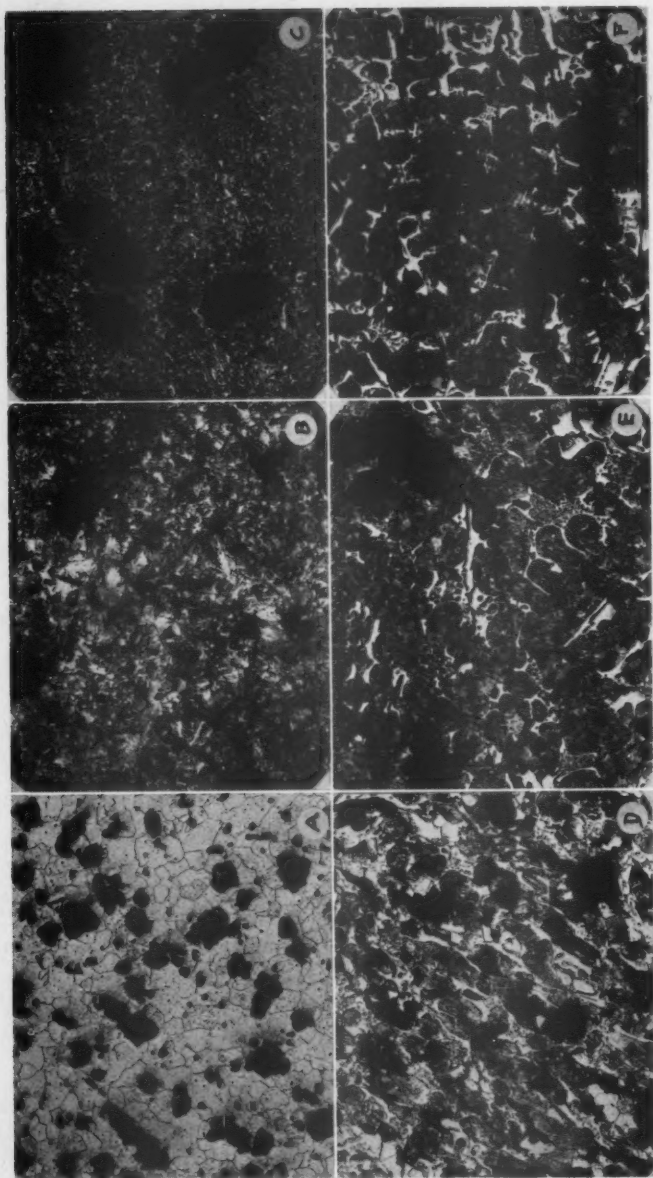


FIG. 17

A—Standard Malleable Iron.

D—Standard Malleable Iron plus 0.31% Ni and 0.27% Cr, Standard Anneal.

B—Standard Malleable Iron—Reheated to 1700°F. for 30 minutes—Cooled in Air.

E—Malleable Iron—Annealed 20 hrs. at 1700°F. —Cooled in furnace to 1400°F., Air Cooled.

C—Standard Malleable Iron—Reheated to 1510°F. Oil Quenched, 900°F. Draw.

F—Malleable Iron—Annealed 15 hrs. at 1700°F. —Air Cooled.

obtained in heavy sections where low silicon irons could be used or in high strength irons resulting from use of low total carbon. Where high total carbon was used and especially in light sections with high silicon, the strength-hardness ratio fell to the right side of the areas shown in Fig. 15.

31. If a composition is out of balance either by lack of silicon or by excess of any carbide forming element so that free carbides form, a less favorable strength to hardness ratio will result. The increase of hardness and loss of strength by presence of free carbides is strikingly illustrated in Fig. 16. This compares the strength-hardness ratio of cast irons with that of malleable iron, pearlitic malleable, heat treated malleable and three incompletely annealed malleable irons containing appreciable amounts of massive carbide persisting from the as cast condition. The top curve is determined by those malleable irons which have no free carbides present and the next lower curve contains the three irons containing free carbides showing definitely the weakening and hardening effect of free carbides. The upper curve might be considered the limit toward which cast iron could be made to approach by controlling the amount of free carbon and making its shape approach the nodular shape existing in malleable iron. The micro-

Table 4
DATA ON MODIFIED MALLEABLE IRONS

Symbol	Treatment	Brinell Hardness No.	Tensile Strength Sq. In. Lbs.	T.C. %	Composition			
					Si %	Mn %	P %	S %
A	Standard Annealing Treatment.....	130	50,000	2.75	1.15	0.45	0.07	0.11
B	Standard Anneal— Reheat to 1700°F. for 30 min. Air Cool.....	248	99,300	2.75	1.16	0.46	0.067	0.094
C	Standard Anneal— Reheat to 1510°F. Oil Quenched 900°F. draw.....	286	121,000	2.75	1.22	0.49	0.071	0.09
D	.31% Ni and 0.27% Cr added Stand- ard Anneal.....	217	66,300	2.76	1.29	0.46	0.077	0.108
E	Annealed 20 hrs. at 1700°F. Cooled in furnace to 1450°F. Air Cooled.....	269	82,000	2.75	1.11	0.42	0.071	0.109
F	Annealed 15 hrs. at 1700°F. Air Cooled.....	286	88,200	2.78	1.13	0.45	0.096	0.096

structure of the six irons used to plot the upper two curves in Fig. 16 are shown in Fig. 17 and their composition and treatment is given in Table No. 4.

32. The ratio of strength to hardness for irons discussed in this paper varies from 73 to 235 not including the malleable and pearlitic malleable irons. The irons with a ratio over 200 are the low carbon high strength irons or else low carbon low silicon irons cast in heavy sections. For sections having a cooling rate similar to a 1.2 in. dia. test bar, the ratio is lower for the softer irons so that a fairly well balanced iron will have a strength-hardness ratio about equal to the brinell hardness. In other words, by squaring the brinell hardness we should get a pretty good idea of what the tensile strength should be in an iron of well balanced composition. This, however, is only a very rough indication. In many cases a satisfactory iron for a particular job will exceed or fall below this figure.

33. It is hoped that the reader has obtained from the foregoing discussion some idea as to the influence of microstructure on the tensile strength and hardness of cast iron.

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(18) F. J. Walls—*Permanent Mold Castings*—Trans. American Foundrymen's Ass'n. Vol. XLII, p. 427 (1934).

(For Discussion See Page 650)

Microstructure and Physical Properties of Alloy Cast Irons

BY V. A. CROSBY*, DETROIT, MICH.

1. Alloying elements in their effects on cast irons may be divided into two general classes: (1) Elements which increase combined carbon and free cementite and (2) those elements which tend to reduce the amount of the common hardening constituents, cementite and pearlite.

2. Elements of the first classification (carbide forming elements) are given below in the order of their intensity:

- (1) Vanadium
- (2) Chromium
- (3) Molybdenum
- (4) Manganese

3. The second series, as referred to in paragraph one, is given below in the order of the effectiveness of the elements as graphitizing agents:

- | | |
|----------------------|--|
| (1) Graphitic Carbon | {Not considered generally as
alloying element in cast iron. |
| (2) Silicon | |
| (3) Titanium | |
| (4) Nickel | |
| (5) Copper | |

4. While there are many more elements which might be included in the two classifications listed above, it was deemed advisable to confine this paper to those elements which have attained some degree of practical importance in the field of commercial applications. Only nickel, chromium, molybdenum, manganese, vanadium and copper are considered in this paper.

5. Although it is not within the scope of this article to treat qualitatively or quantitatively the specific contribution of each alloying element to the science of cast iron metallurgy, it is felt that a general resumé should be made. To those keenly interested in the properties of special and alloyed irons the existing literature affords more or less exhaustive information, and for this reason it is considered feasible to refer to the various alloying elements in cast iron in a general way and to the case histories and data available concerning each in a very specific manner.

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FACTORS AFFECTING PHYSICAL PROPERTIES

6. The physical properties of cast iron depend upon the amount and distribution of the graphite (in the case of gray irons) and upon the composition and structure of the matrix, however, one who presumes to predict physical properties within close limits is, to say the least, overstepping the conservative bounds of propriety.

7. Only very general predictions can be drawn from close observations of photomicrographs of unetched and etched specimens. Additional information in the form of chemical analyses greatly enhances ones ability to predict physical properties and service behavior of specimens.

8. Along with the above data, if a complete log of the heat from which the specimens were taken is available, with the log containing methods of melting, character of charge, degree of super-heat, slag characteristics, pouring temperature, kind of mold used, whether late additions (graphitizing agents) were used and size of section under consideration, it is anticipated that a reasonable degree of evaluation of cast irons may be attained.

Constitutional Diagram of Iron Carbon Alloys

9. The constitutional diagram of iron carbon alloys in the range commonly referred to as cast irons has been worked out by Maurer and is shown in Fig. 1. This diagram is based upon information obtained from a given test bar size involving a constant cooling rate where presumably the only variable is composition. The Maurer diagram may be considered fairly accurate for carbon compositions less than four per cent, and may be considered suitable for sections ranging from one to one and one-quarter inches; larger sections would automatically shift all lines to the left and smaller sections to the right.

10. The effect of carbide forming elements on cast iron would be similar to that associated with a smaller section test bar, i. e., that all lines would be shifted to the right, conversely graphitizing agents would shift the areas bounded by certain lines to the left, making it possible, as it were, to obtain gray iron in an area nominally white.

11. The volume of nickel sold to the foundry industry and the important position of nickel as an alloying element in this field justifies its claim to first position.

12. Briefly, nickel is a graphitizing agent, a nominal graphite

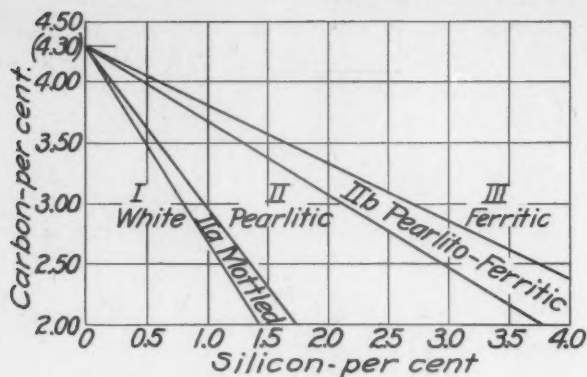


FIG. 1—MAURER DIAGRAM

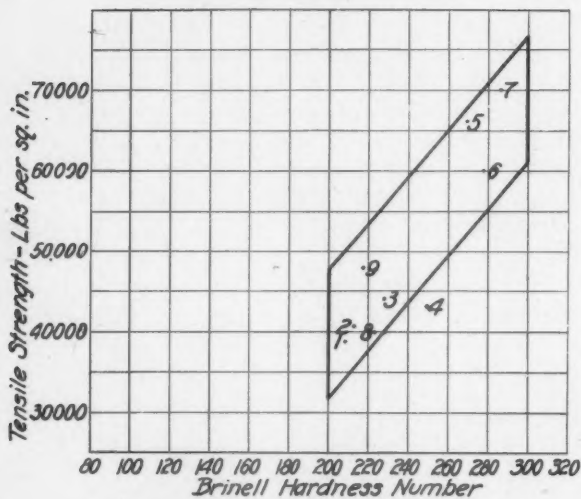


FIG. 2—NICKEL CAST IRON TESTS ON A. S. T. M. TYPE H BARS

Bar No.	T.C. %	C.C. %	G.C. %	Mn. %	Si. %	P. %	S. %	Ni. %	Ten. Str. lb. per sq. in.	BHN No.	Process
1	3.33	0.69	2.64	0.68	1.82	0.20	0.07	.72	39,000	207	Electric
2	3.27	0.66	2.61	0.69	1.86	0.20	0.07	1.39	41,000	212	Electric
3	3.23	0.70	2.53	0.66	1.89	0.20	0.07	2.75	44,000	228	Electric
4	2.87	0.78	2.09	0.70	1.22	0.10	0.10	2.24	43,000	248	Cupola
5*	2.76	0.63	2.13	0.63	1.91	0.12	0.07	0.66	66,000	269	....
6*	2.78	0.78	2.00	0.83	1.91	0.10	0.09	2.48	60,000	277	....
7*	2.73	0.62	2.11	0.65	2.59	0.12	0.07	1.11	70,400	286	....
8*	3.30	0.77	2.53	0.75	1.01	0.10	0.12	1.05	40,000	233	Cupola
9*	2.86	0.51	2.35	1.02	2.79	0.01	0.01	1.07	48,400	217	Electric

*International Nickel Co. Tests.

refining element, a ferrite hardening constituent; all of which promote better machining at a given hardness or the same machining characteristics at higher brinell hardnesses, better wear resistance due to increased hardness of the ferrite in the pearlite and greater service life due to increased strength. The effect of nickel in cast iron would result in a shift of all lines toward the left in the Maurer diagram.

13. The block chart, Fig. 2, shows the relationship between brinell hardness and tensile strength, which is to say the least a trend curve dependent very largely upon the base iron used. The better base irons fall along the top lines and the poorer base irons, in spite of the alloy additions, along the lower lines of the block chart. In part one of this paper Boegehold has plotted similar charts using only plain iron, showing in like manner the general trend of a curve if drawn. The interesting point in comparison with this and succeeding charts in this paper is the fact that the alloy irons are over to the right and up, indicating in part the better base irons produced when alloys are used and also the inherent effect of the alloys in producing stronger iron with a given base.

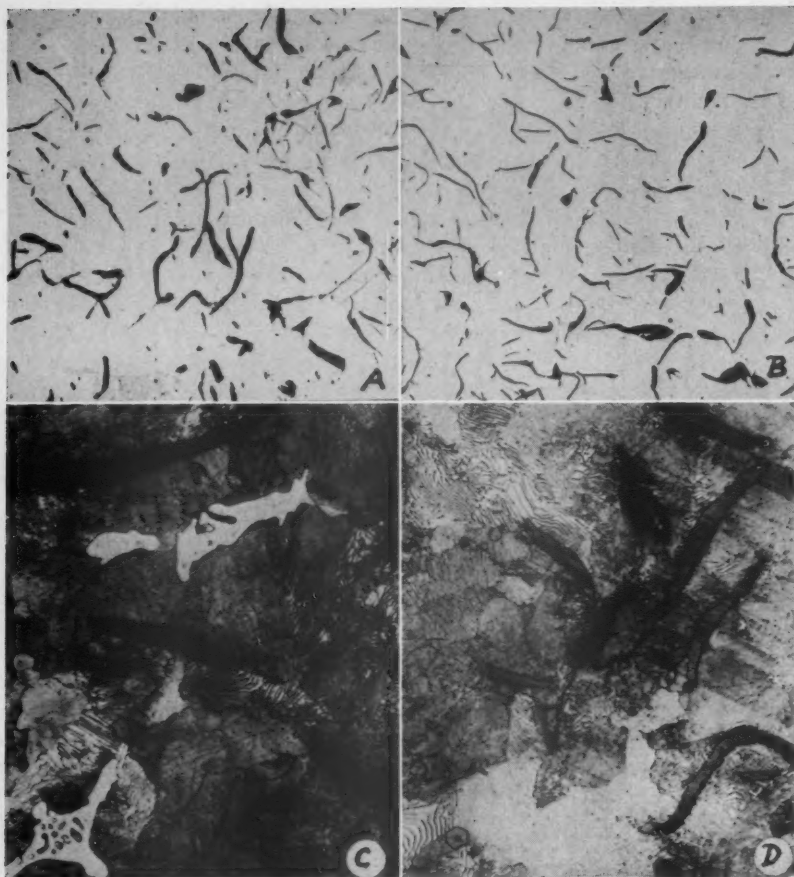
14. Fig. 3 illustrates an unserviceable iron made serviceable and machinable by the addition of nickel. Probably it is a little incorrect to state that this iron is unserviceable, but rather that a difficult machining problem is presented in this type of iron which is corrected by the addition of nickel in the proportion of two to one. Note the change in carbide structure to fine pearlite.

15. Fig. 4 shows the effect of nickel in a pearlitic cast iron. Note the refinement of the graphite and the tendency toward a sorbitic matrix.

CHROMIUM

16. Chromium is essentially a carbide forming element when used in cast irons of the gray variety. Its use results in increased hardness, increased strength up to certain limits, increased difficulty in machining proportional to the amount of chromium added, increased resistance to heat effects and increased wear resistance. It tends to shift the lines of the Maurer diagram toward the right.

17. In unbalanced irons containing free ferrite, an addition of chromium is quite beneficial in eliminating this constituent and in producing an all pearlitic iron with consequent improvement in strength, wear resistance and general serviceability. Fig. 5 illustrates the advantages enumerated above.



Cr. Iron (A) and (C)

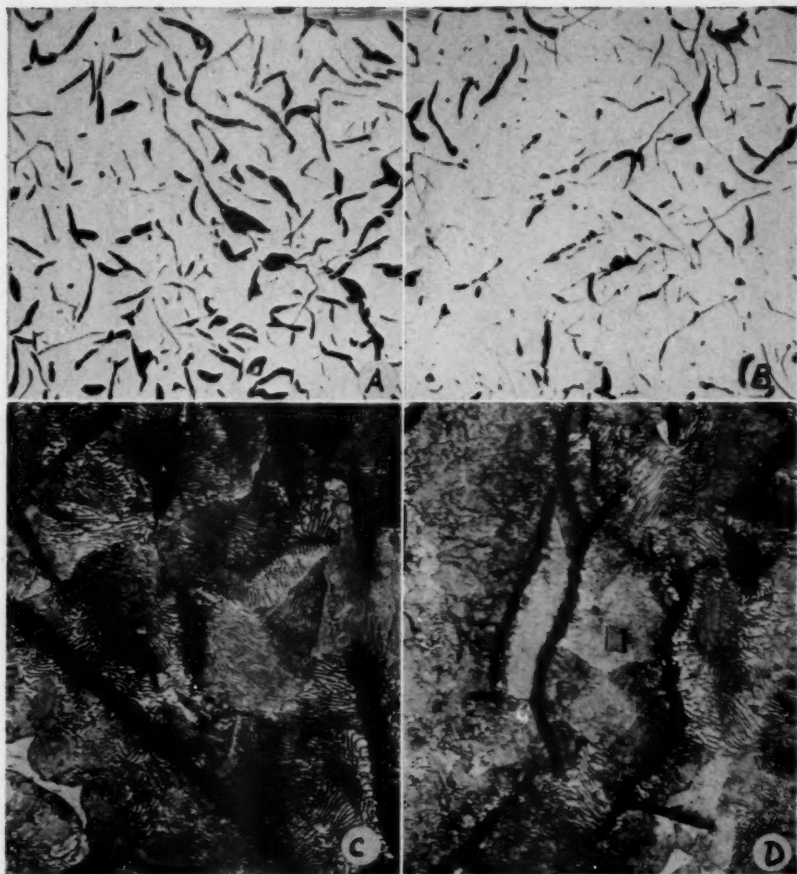
Cr.-Ni. Iron (B) and (D)

(A) X100 Unetched — (C) X500 Etched 2% Nital

(B) X100 Unetched — (D) X500 Etched 2% Nital

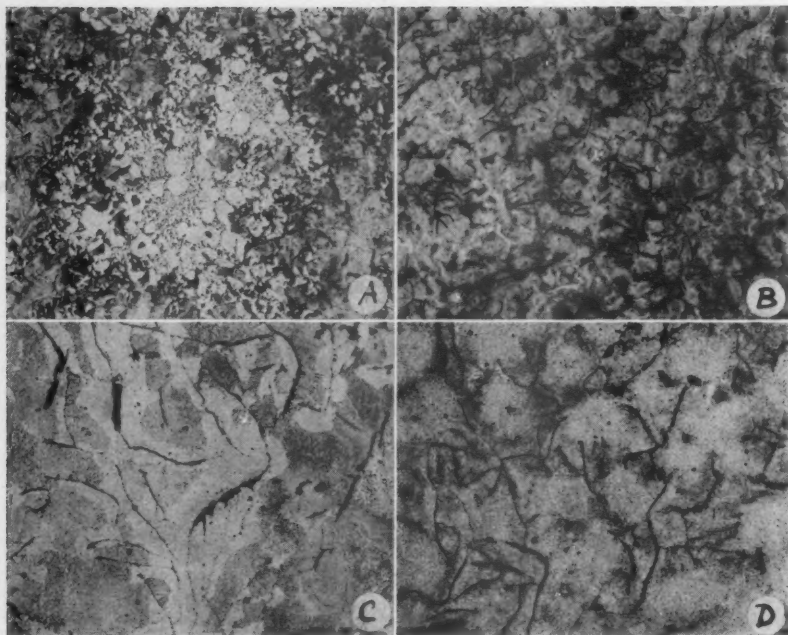
Analysis	Cr. Iron %	Cr.-Ni. Iron %	Physical Properties	Cr. Iron	Cr.-Ni. Iron
T.C.	3.10	3.07	Transverse (lb.).....	2,980	3,220
C.C.	1.07	0.77	Deflection (in.).....	0.228	0.287
G.C.	2.03	2.30	Ten. Str. (lb. per sq. in.).....	46,200	48,900
Mn.	0.84	0.83	Brinell (No.).....	255	248
Si.	2.21	2.27			
S.	0.08	0.08			
P.	0.07	0.07			
Cr.	0.86	0.84			
Ni.	....	1.53			

FIG. 3—CUPOLA PROCESS CR. AND NI-CR. IRONS



Plain Iron (A) and (C)			Nickel Iron (B) and (D)		
(A) X100 Unetched—(C) X500 Etched 2% Nital			(B) X100 Unetched—(D) X500 Etched 2% Nital		
Analysis	Plain Iron %	Nickel Iron %	Physical Properties	Plain Iron	Nickel Iron
T.C.	3.33	3.23	Transverse (lb.)	2,560	2,760
C.C.	0.69	0.70	Deflection (in.)	0.305	0.288
G.C.	2.64	2.53	Ten. Str. (lb. per sq. in.)	38,710	44,000
Mn.	0.68	0.66	Brinell (No.)	202	228
Si.	1.82	1.89			
Ni.	....	2.75			

FIG. 4—ROCKING ELECTRIC PROCESS PLAIN AND NICKEL IRONS

**Plain Iron (A) and (C)**

(A) $\frac{3}{4}$ in. Round Section, Etched X100
 (C) 6.5 in. Round Section, Etched X100

Cr. Iron (B) and (D)

(B) $\frac{3}{4}$ in. Round Section, Etched X100
 (D) 6.5 in. Round Section, Etched X100

Analysis	Plain Iron %	Cr. Iron %
T.C.	2.80	2.98
C.C.	0.46	0.57
Si.	2.55	2.57
Mn.	0.77	0.80
Cr.	....	0.79
P.	0.24	0.24
S.	0.09	0.09

FIG 5—PLAIN IRON AND CR. IRON—CUPOLA PROCESS (ELECTRO METALLURGICAL CO.)

18. Where carbon and silicon ratios are such that a fine pearlitic iron is obtained an addition of chromium tends to produce free carbides which become quite objectionable as the amount of chromium approaches 0.50 to 0.85 per cent. This situation is illustrated in Fig. 6. The white areas shown in the etched alloy iron microstructure are carbides of iron and chromium.

19. Fig. 7 shows the general relationship between brinell hardness and strength of a series of chromium cast irons, of which fairly complete data were available. The data indicate that chromium increases hardness at a higher rate than it increases strength. This conclusion is justified only when one considers that chromium, because of the very nature of its action in gray irons, is not used in the most desirable base irons for greatest strength. Its greatest application seems to be in that field where both carbon and silicon are medium to high.

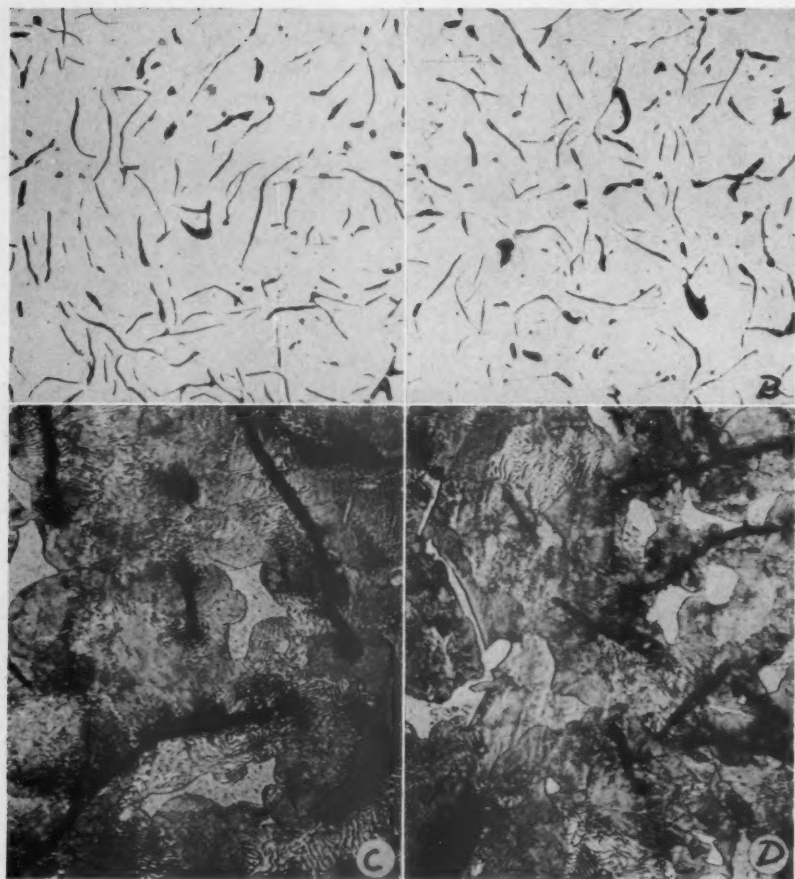
MOLYBDENUM

20. While molybdenum is listed as a carbide forming element in cast iron, its action in effect is that of a mild carbide stabilizer. In some types of iron as much as 1.0 per cent Mo. may be added with no increase in combined carbon content. Such effect would lead one to believe that its solid solution characteristics seem to be of much greater importance than the carbide phase, as revealed by combined carbon. The above statement is particularly true when one is dealing with a composition and section which is just barely of eutectoid composition.

21. Molybdenum may be added to an unbalanced iron containing free ferrite with beneficial effect in producing a pearlitic structure and increasing the tensile and transverse properties. It may likewise act in a very potent manner when added to a well balanced pearlitic iron with no deleterious effects from massive carbides. Molybdenum has a slight tendency to shift the lines of the Maurer diagram toward the right.

22. Fig. 8 shows the structural changes accompanying a 0.63 per cent Mo. addition to an ordinary grade of cast iron. The structure of the plain iron is shown for comparison. Details as to process of melting and producing are listed with the data.

23. Fig. 9 shows an iron of similar carbon content but lower silicon containing 0.98 per cent molybdenum. This structure is known as acicular pearlite and seems to develop in irons containing approximately 1.00 per cent Mo. or more. The slight drop in



Plain Iron (A) and (C)			Chromium Iron (B) and (D)		
(A) X100 Unetched—(C) X500 Etched 2% Nital			(B) X100 Unetched—(D) X500 Etched 2% Nital		
Analysis	Plain Iron %	Chromium Iron %	Physical Properties	Plain Iron	Chromium Iron
T.C.	3.30	3.32	Transverse (lb.).....	2,550	2,980
C.C.	0.64	0.87	Deflection (in.).....	0.280	0.263
G.C.	2.66	2.45	Ten. Str. (lb. per sq. in.).....	39,900	46,600
Mn.	0.73	0.73	Brinell (No.).....	217	241
Si.	1.84	1.89			
S.	0.11	0.11			
P.	0.17	0.16			
Cr.	0.05	0.88			

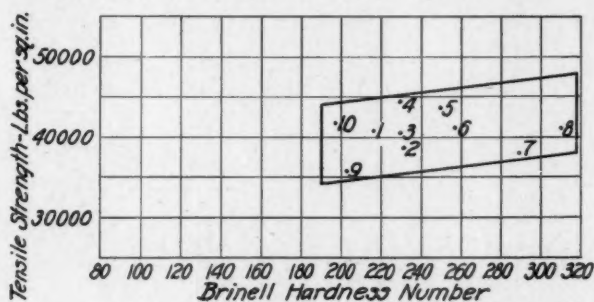
FIG. 6—ROCKING ELECTRIC PROCESS PLAIN AND CHROMIUM IRONS

tensile values noted in the case of the Ni-Mo. iron is most probably associated with the dendritic graphite formation noted in the etched photomicrograph. The large dark areas noted in the Mo. iron are, doubtless, troostite. An acicular pearlitic structure is quite prominent in each case. Certain alloy combinations enable one to secure this structure with much lower molybdenum, as illustrated in Fig. 10. Acicular pearlite, as shown in the etched photomicrograph in this figure, is obtained in $\frac{1}{8}$ -in. sections and likewise in 2-in. sections by the use of a combination of Cu. and Mo. and Mn. and Mo. respectively. The constituent, acicular pearlite is most desirable for maximum impact properties.

24. Fig. 11 shows the effect of 1.0 per cent Mo. in a very high carbon, high silicon cast iron. The same general type of acicular pearlite is present. Note the complete absence of massive carbides as well as the presence of some austenite in these structures. The latter are revealed as white structureless areas.

25. Fig. 12 shows a very unusual type of cast iron; high in silicon, manganese and molybdenum. The structure closely resem-

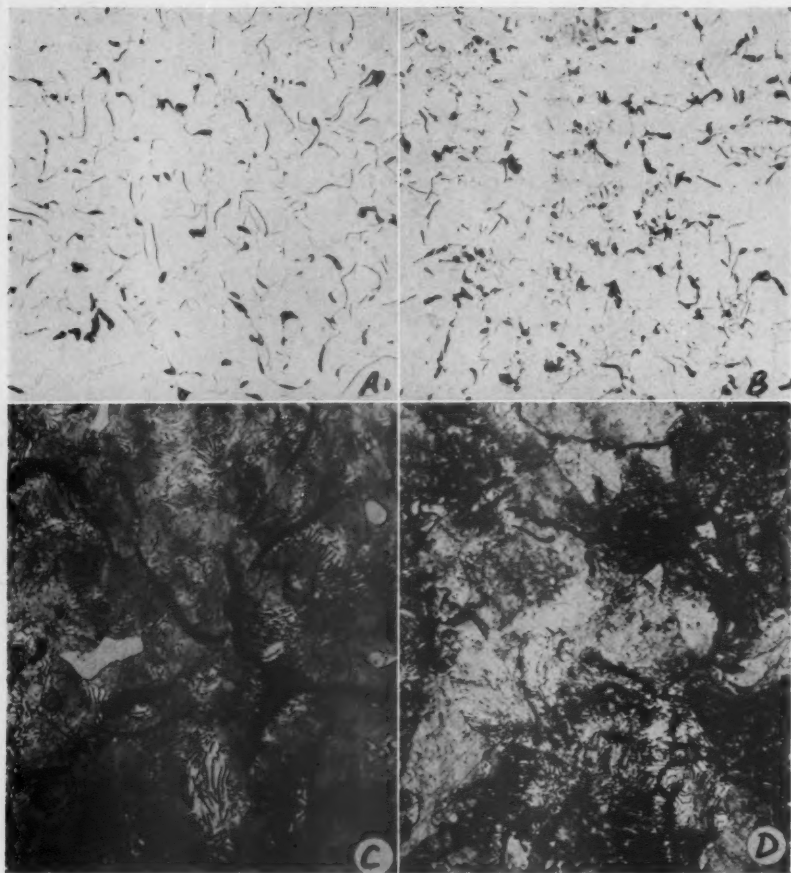
FIG. 7—CHROMIUM CAST IRON TESTS ON A. S. T. M. TYPE B BARS



Bar. No.	T.C. %	C.C. %	G.C. %	Mn. %	Si. %	S. %	P. %	Cr. %	Ten. Str. lb. sq. in.	BHN No.	Process
1*	2.98	0.57	2.41	0.80	2.57	0.09	0.24	0.79	41,600	217	....
2*	3.28	0.66	2.62	....	....	....	....	0.77	39,700	228	....
3	3.30	0.66	2.64	0.73	1.84	0.11	0.17	0.36	41,600	228	Electric
4	3.32	0.73	2.59	0.71	1.81	0.11	0.16	0.66	45,000	228	Electric
5	3.32	0.87	2.45	0.74	1.86	0.11	0.17	0.88	44,100	248	Electric
6	3.29	0.69	2.60	0.47	1.89	0.06	0.18	0.52	41,800	255	Electric
7**	3.24	1.19	2.05	0.66	1.93	0.12	0.18	1.41	38,000	286	Cupola
8**	2.98	1.41	1.57	0.88	2.07	0.09	0.13	1.33	41,600	311	Electric
9	3.29	0.61	2.68	0.67	2.21	0.12	0.14	0.26	36,100	202	Cupola
10	3.08	0.60	2.48	0.63	2.52	0.10	0.18	0.18	42,100	196	Cupola

*Electro-Metallurgical Corp.

**Studebaker Corp.

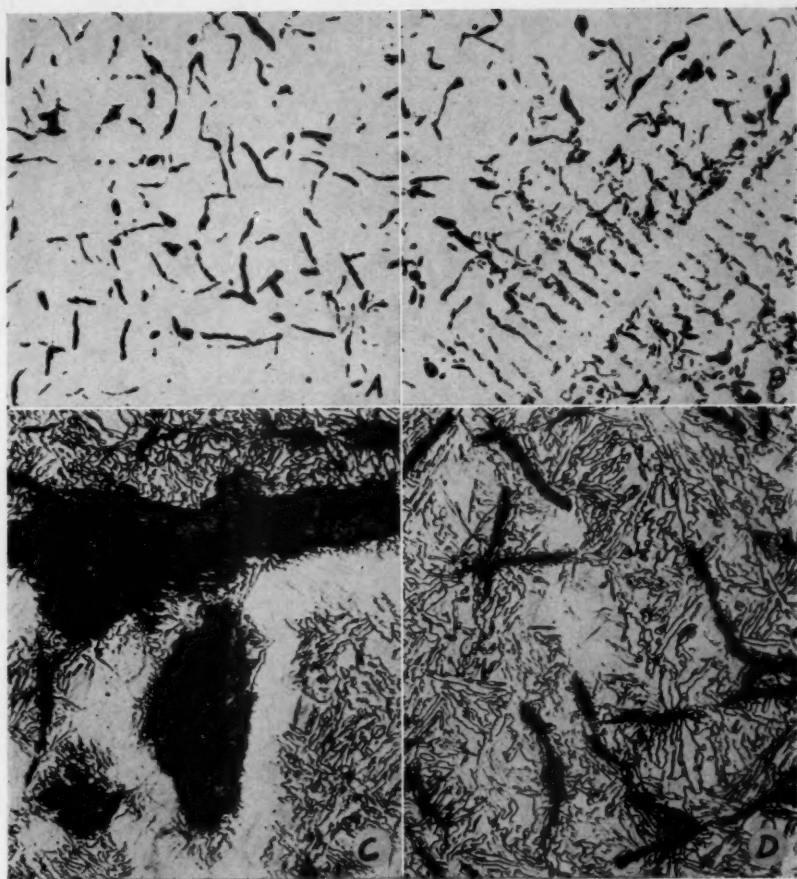
**Plain Iron (A) and (C)****Molybdenum Iron (B) and (D)**

(A) X100 Unetched—(C) X500 Etched 2% Nital

(B) X100 Unetched—(D) X500 Etched 2% Nital

Analysis	Plain Iron %	Molyb- denum Iron %	Physical Properties	Plain Iron	Molyb- denum Iron
T.C.	3.31	3.27	Transverse (lb.) (ASTM Type "B")	2,500	3,015
C.C.	0.70	0.72	Deflection (in.)	0.262	0.289
G.C.	2.61	2.55	Ten. Str. (lb. per sq. in.)	42,000	51,300
Mn.	0.84	0.86	Brinell (No.)	217	235
Si.	1.81	1.89			
S.	0.087	0.09			
P.	0.159	0.159			
Mo.	....	0.63			

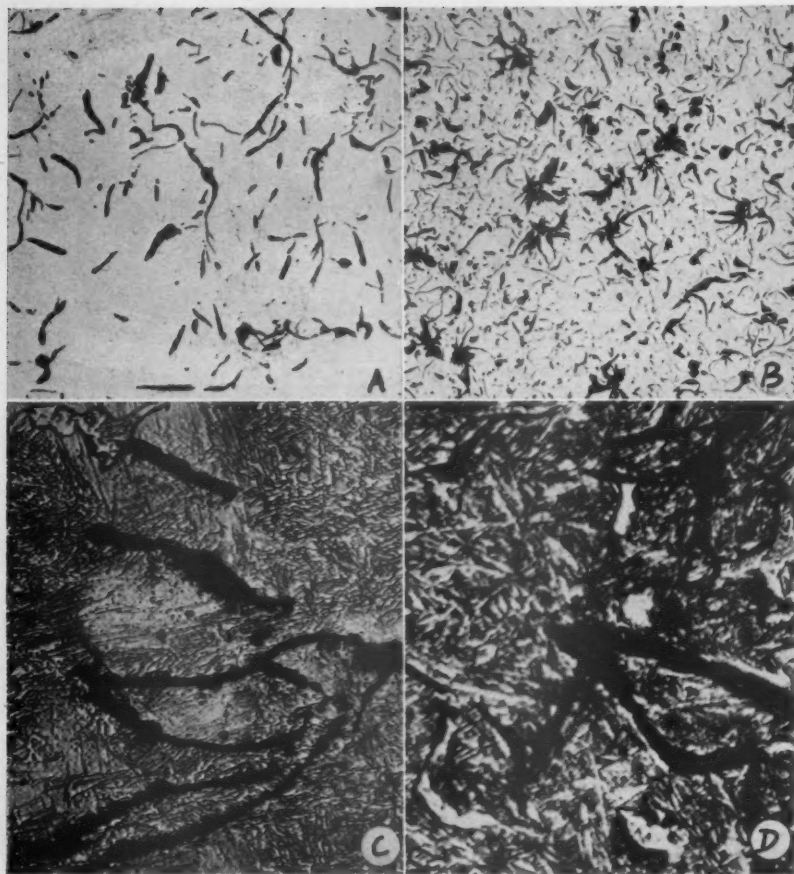
FIG. 8—INDUCTION ELECTRIC PROCESS PLAIN AND MOLYBDENUM IRONS

**Mo. Iron (A) and (C)****Ni-Mo. Iron (B) and (D)**

(A) X100 Unetched—(C) X500 Etched 2% Nital (B) X100 Unetched—(D) X500 Etched 2% Nital

Analysis	Mo. Iron %	Ni-Mo. Iron %	Physical Properties	Mo. Iron	Ni-Mo. Iron
T.C.	3.25	3.22	Transverse (lb.).....	3,080	3,048
C.C.	0.71	0.75	Deflection (in.).....	0.283	0.295
G.C.	2.54	2.47	Ten. Str. (lb. per sq. in.).....	60,000	56,500
Mn.	0.86	0.84	Brinell (No.).....	241	255
Si.	1.54	1.55			
Mo.	0.88	0.98			
Ni.	....	1.22			

FIG. 9—INDUCTION ELECTRIC PROCESS MO. AND NI-MO. IRONS



Mn.-Mo. Iron 2" Sec. (A) and (C)			Cu.-Mo. Iron 1/8" Sec. (B) and (D)		
(A) X100 Unetched—(C) X500 Etched 2% Nital			(B) X100 Unetched—(D) X1500 Etched 2% Nital		
Analysis	Mn.-Mo. Iron %	Cu.-Mo. Iron %	Physical Properties	Mn.-Mo. Iron	Cu.-Mo. Iron
T.C.	2.90	3.57	Transverse (lb.).....	13,700	....
C.C.	0.67	0.62	Deflection (in.).....	0.291	....
G.C.	2.23	2.95	Ten. Str. (lb. per sq. in.).....	72,600	....
Mn.	1.58	0.55	Brinell (No.).....	302	255
Si.	2.52	3.07			
S.	....	0.06			
P.	....	0.35			
Cu.	....	0.85			
Mo.	1.51	0.43			

FIG. 10—ELECTRIC PROCESS MN.-MO. IRON AND CUPOLA PROCESS CU.-MO. IRON

**Mo. Iron (A) and (C)****Ni-Mo. Iron (B) and (D)**

(A) X100 Unetched—(C) X500 Etched 2% Nital			(B) X100 Unetched—(D) X500 Etched 2% Nital		
Analysis	Mo. Iron %	Ni-Mo. Iron %	Physical Properties	Mo. Iron	Ni-Mo. Iron
T.C.	3.48	3.43	Transverse (lb.).....	3,389	3,663
C.C.	0.80	0.82	Deflection (in.).....	0.423	0.549
G.C.	2.68	2.61	Ten. Str. (lb. per sq. in.).....	48,900	48,800
Mn.	0.85	0.85	Brinell (No.).....	255	255
Si.	2.52	2.47	Impact (ft. lbs.).....	37.5	61.0
Mo.	1.01	1.01			
Ni.	....	1.05			

FIG. 11—INDUCTION ELECTRIC PROCESS MO. AND NI-MO. IRONS

bles martensite with some austenitic areas present which transform to martensite on a 1050° F. draw, the hardness increasing about 40 to 50 BHN. The iron shown on the left side of this figure is quite low in carbon and high in molybdenum. It is interesting to note the uniformity of hardness from 1.2-in. section to center of 2.0-in. section. The transverse, tensile and impact properties are not quite as good as obtained in the higher carbon iron shown on the right.

26. Fig. 13 shows the relationship between brinell hardness and tensile strength taken from a large number of irons containing only molybdenum. The table in the caption for Fig. 13 gives full data pertaining to analyses and physical properties.

27. Fig. 14 shows the refining action of a chromium-molybdenum addition on the graphitic structure and the sorbitizing effect on the matrix. These effects are reflected in the physical properties given in the caption of the figure.

COPPER

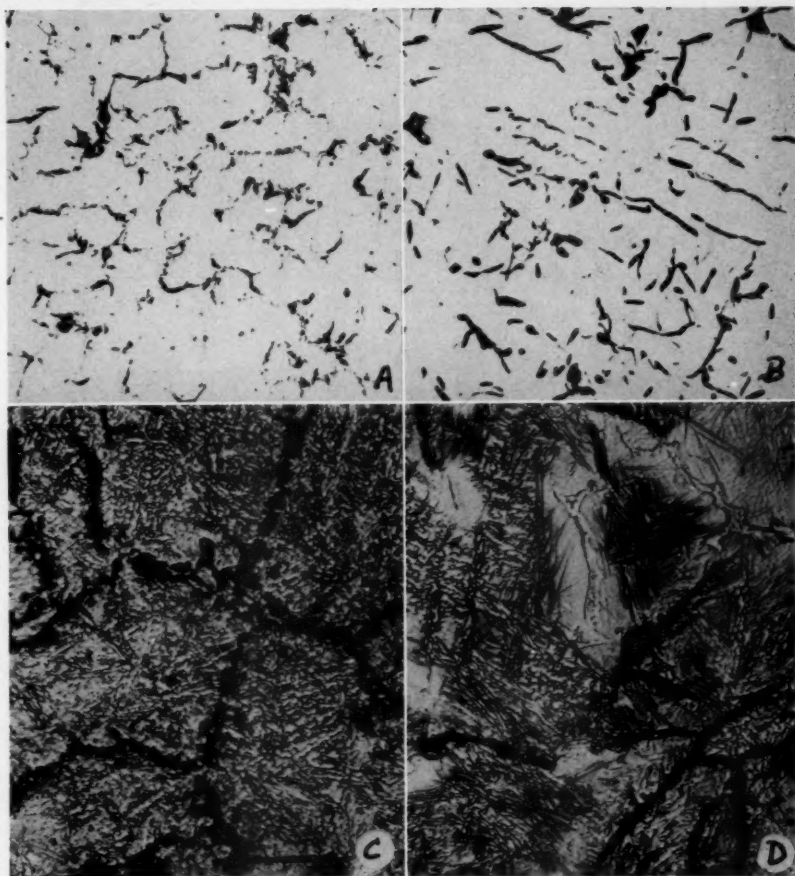
28. Copper is a mild graphitizing agent, considered in general about one-half to one-third as effective as nickel. It increases hardness and, to a small extent, tensile strength. It is said to increase fluidity in very low carbon cast irons. Very little effect is noted in higher carbon irons. Since copper acts somewhat like nickel, one would expect a similar shift in the Maurer diagram.

29. Fig. 15 shows compiled data and relationship between hardness and strength of a wide range of copper cast irons. There are some indications that, in a given base iron, copper additions will slightly increase tensile strength.

30. Fig. 16 shows the change in microstructure resulting from a 3.00 per cent addition of copper to an iron normally running around 40,000 lb. per sq. in.

MANGANESE

31. Manganese in the normal range of 0.35 to 0.90 per cent cannot be classified as an alloying element and perhaps it is a bit presumptive to place it in this discussion at all. However, it appears that more and more people are taking advantage of the strengthening effect of manganese in high strength cast iron where the percentage will vary from 0.90 to 1.75 per cent, so the author has concluded that it is not amiss to put in a few paragraphs per-

**High Mo.-Low C. Iron (A) and (C)**

(A) X100 Unetched—(C) X500 Etched 2% Nital

Analysis	High Mo.	High Mo.
	Low C.	Med. C.
	%	%
T.C.	2.19	2.90
C.C.	0.61	0.67
G.C.	1.58	2.23
Mn.	0.99	1.58
Si.	3.16	2.52
Mo.	1.41	1.51

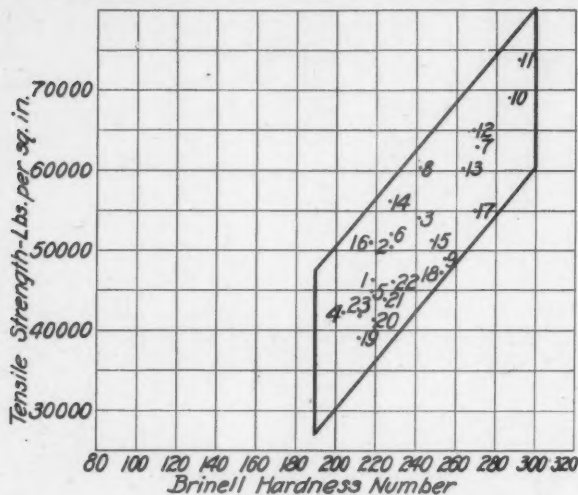
High Mo.-Med. C. Iron (B) and (D)

(B) X100 Unetched—(D) X500 Etched 2% Nital

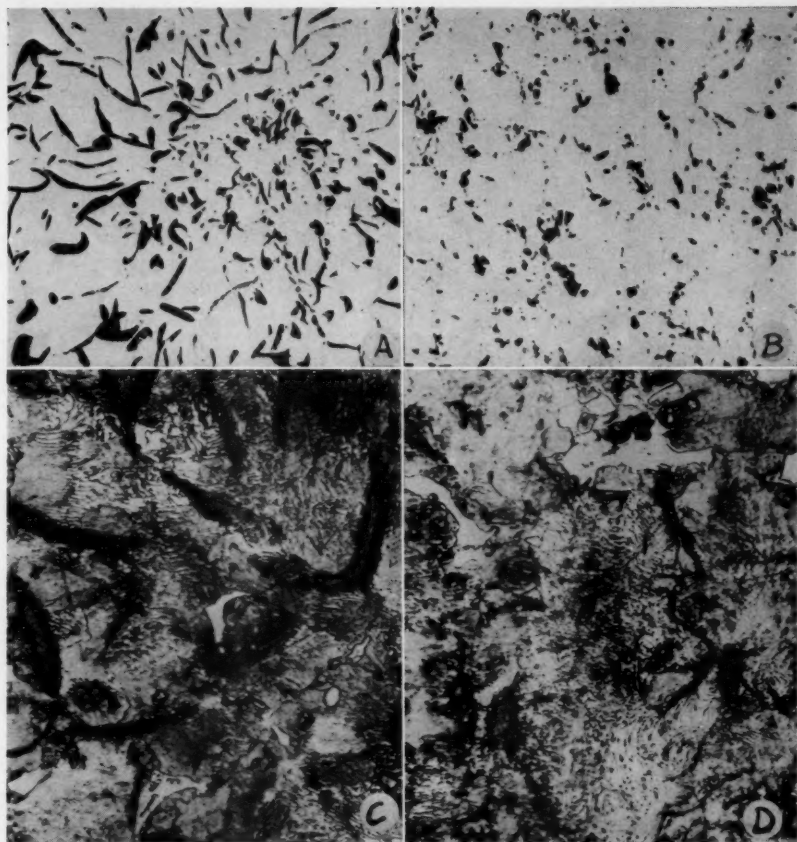
Physical Properties	High Mo.	High Mo.
	Low C.	Med. C.
Transverse (lb.).....	3,580	4,025
Deflection (in.)	0.280	0.354
Ten Str. (lb. per sq. in.).....	73,260	74,750
(1.2" bar)		
Brinell (No.).....	331	341
Ten. Str. (lb. per sq. in.).....	66,880	72,600
(2.0" bar)		
Brinell (No.).....	331	302
Impact (ft. lbs.).....	51.5	71.1

FIG. 12—INDUCTION ELECTRIC PROCESS HIGH MO.-LOW C. AND HIGH MO.-MED. C. IRONS

FIG. 13—MOLYBDENUM CAST IRON TESTS OF A. S. T. M. TYPE B BARS 1.20 IN. IN DIAMETER.



Bar No.	T.C. %	C.C. %	G.C. %	Mn. %	Si. %	P. %	Si. %	Mo. %	Ten.Str. lb. per sq. in.	BHN No.	Process
1	3.31	.70	2.61	.84	.08	.16	1.81	.29	45,800	217	Electric
2	3.27	.72	2.55	.86	.09	.15	1.89	.63	51,300	228	Electric
3	3.24	.70	2.54	.83	.08	.15	1.79	1.03	54,600	241	Electric
4	3.30	.65	2.65	.76	.11	.17	1.93	.30	42,200	205	Electric
5	3.26	.69	2.57	.73	.11	.17	1.91	.68	45,750	217	Electric
6	3.26	.76	2.50	.74	.11	.17	2.00	.93	51,500	228	Electric
7	2.85	.67	2.18	.86	.05	.05	2.33	1.03	63,800	269	Electric
8	3.25	.71	2.54	.86	.05	.05	1.54	.98	60,000	241	Electric
9	3.48	.80	2.68	.85	.05	.05	2.52	1.01	48,800	255	Electric
10	2.86	.75	2.11	.85	.05	.05	1.62	1.00	69,100	286	Electric
11	2.90	.67	2.23	1.51	.03	.05	2.52	1.51	74,750	302	Electric
12	2.66	.68	1.98	.88	.08	.17	2.62	.62	65,120	269	Cupola-Electric
13	3.16	.72	2.44	1.08	.09	.09	1.36	.78	60,100	269	Cupola
14	3.44	.77	2.67	.83	.00	.03	1.44	.55	56,000	228	Electric
15	3.31	.72	2.59	.88	.09	.15	1.73	.51	51,000	248	Cupola-Electric
16	2.96	.66	2.30	.73	.12	.12	2.17	.48	51,000	217	Electric
17	3.24	.76	2.48	.89	.01	.09	2.43	1.45	55,000	269	Electric
18	3.56	.83	2.73	.94	.02	.09	1.33	.98	47,000	255	Electric
19	3.31	.63	2.68	.67	.12	.18	2.02	.11	39,000	212	Cupola
20	3.27	.61	2.66	.63	.12	.18	2.06	.23	41,200	217	Cupola
21	3.23	.67	2.56	.73	.11	.16	1.96	.36	44,000	223	Cupola
22	3.26	.71	2.55	.76	.13	.18	1.93	.55	46,000	248	Cupola
23	3.19	.61	2.58	.67	.11	.31	2.35	.33	46,400	212	Cupola

**Plain Iron (A) and (C)****Cr.-Mo. Iron (B) and (D)**

(A) X100 Unetched—(C) X500 Etched 2% Nital			(B) X100 Unetched—(D) X500 Etched 2% Nital		
Analysis	Plain Iron %	Cr.-Mo. Iron %	Physical Properties	Plain Iron	Cr.-Mo. Iron
T.C.	3.32	3.28	Transverse (lb.).....	2,200	2,880
C.C.	0.57	0.70	Deflection (in.).....	0.267	0.301
G.C.	2.75	2.58	Ten. Str. (lb. per sq. in.).....	37,400	45,700
Mn.	0.71	0.73	Brinell (No.).....	217	241
Si.	2.28	2.21			
S.	0.09	0.09			
P.	0.16	0.16			
Cr.	....	0.51			
Mo.	....	0.36			

FIG. 14—CUPOLA DUPLEX PROCESS PLAIN AND CR.-MO. IRONS

taining to its general classification, also something about the structure and physical properties of some high manganese irons.

32. Manganese is a mild carbide forming element and exerts quite a tendency toward the retention of austenitic structure. Manganese in the range from 0.90 to 3.00 per cent increases hardness and strength. Some increase in difficulty of machining is noted in the higher manganese contents.

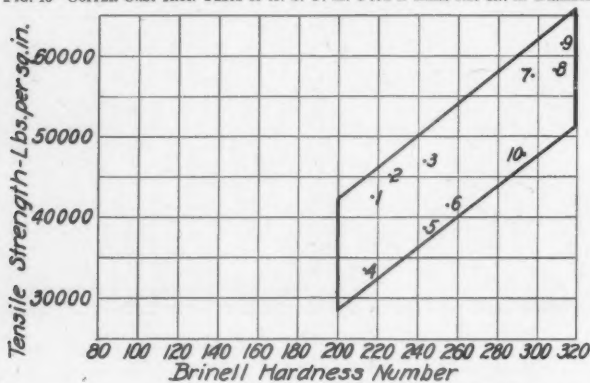
33. Fig. 17 shows data and relationship between hardness and tensile strength of various manganese irons.

34. Fig. 18 shows the structure of plain and 3.00 per cent manganese irons, all other factors the same. Of particular interest is the fact that high manganese addition has not resulted in much massive carbide in the structure. A rather pronounced sorbitizing effect is noted in the matrix.

VANADIUM

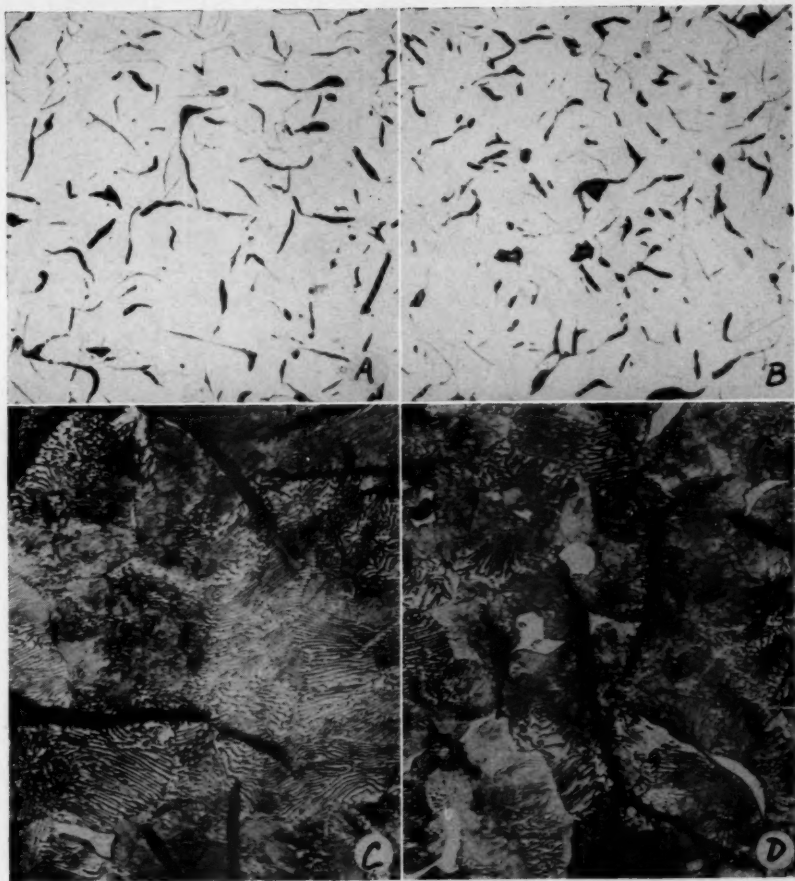
35. Vanadium exerts a very strong carbide stabilizing effect and for that reason is known as one of the potent carbide forming

FIG. 15—COPPER CAST IRON TESTS OF A. S. T. M. TYPE B BARS 1.20 IN. IN DIAMETER.



Bar No.	T.C. %	C.C. %	G.C. %	Si. %	S. %	P. %	Cu. %	Ten. Str. lb. per sq. in.	BHN No.	Process
1	3.21	0.66	2.55	1.96	0.08	.144	.73	43,000	217	Electric
2	3.24	0.69	2.55	1.93	0.08	0.151	1.45	45,000	228	Electric
3	3.00	0.77	2.32	1.91	0.09	0.147	3.03	46,200	241	Electric
4*	3.45	0.64	2.81	1.23	0.09	0.22	1.00	33,300	217	Cupola
5*	3.47	0.68	2.79	1.19	0.09	0.23	2.10	38,000	241	Cupola
6*	3.25	0.73	2.52	1.11	0.10	0.24	3.05	42,000	255	Cupola
7*	3.02	1.07	1.95	1.57	0.14	0.03	1.30	58,000	296	Cupola
8*	2.99	0.99	2.00	1.58	0.14	0.03	2.48	58,000	308	Cupola
9*	2.89	0.87	2.02	1.57	0.12	0.03	3.60	61,000	308	Cupola
10*	3.08	0.85	2.23	1.59	0.11	0.03	2.34	48,000	293	Cupola

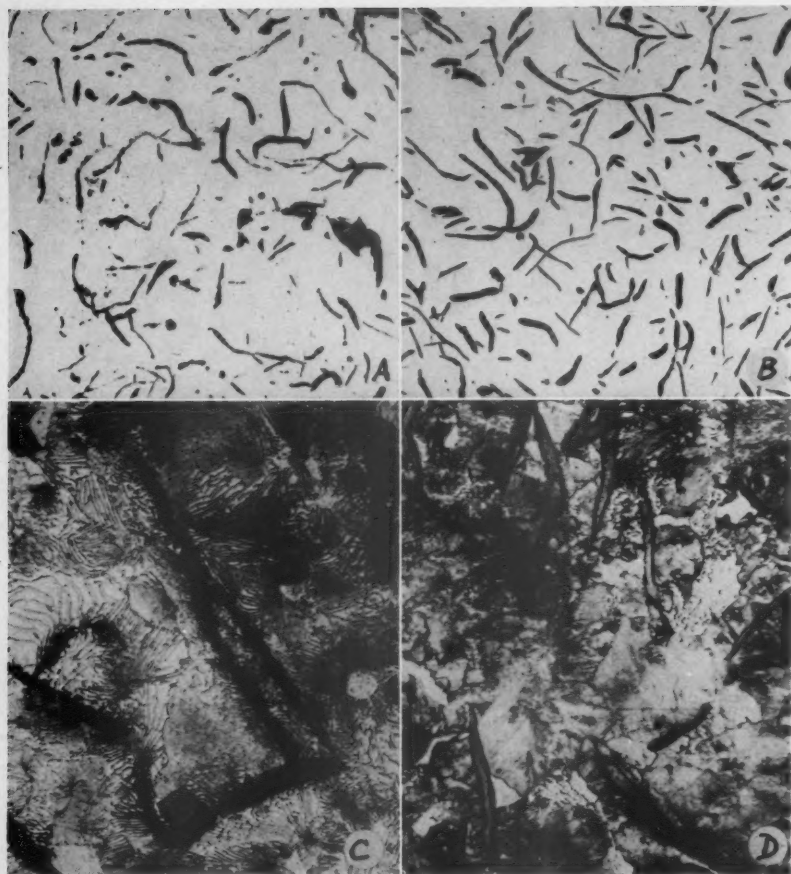
*Data taken from paper by Eastwood, Bousu and Eddy, Trans. A. F. A., Vol. 44, pp. 58-59.

**Plain Iron (A) and (C)****Copper Iron (B) and (D)**

(A) X100 Unetched—(C) X500 Etched 2% Nital (B) X100 Unetched—(D) X500 Etched 2% Nital

Analysis	Plain Iron %	Copper Iron %	Physical Properties	Plain Iron	Copper Iron
T.C.	3.21	3.09	Transverse (lb.).....	2,430	2,980
C.C.	0.66	0.77	Deflection (in.).....	0.372	0.281
G.C.	2.55	2.32	Ten. Str. (lb. per sq. in.).....	40,750	46,000
Mn.	0.67	0.60	Brinell (No.).....	212	241
Si.	1.96	1.91			
Cu.	....	3.03			

FIG. 16—ROCKING ELECTRIC PROCESS PLAIN AND COPPER IRONS

**Plain Iron (A) and (C)****High Mn. (B) and (D)**

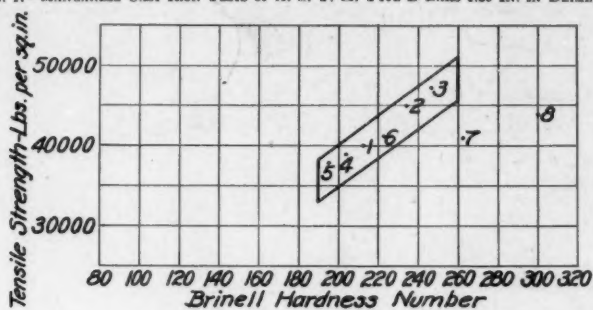
(A) X100 Unetched—(C) X500 Etched 2% Nital

(B) X100 Unetched—(D) X500 Etched 2% Nital

Analysis	Plain Iron %	High Mn. Iron %	Physical Properties	Plain Iron	High Mn. Iron
T.C.	3.28	3.34	Transverse (lb.).....	2,340	2,395
C.C.	0.60	0.62	Deflection (in.).....	0.272	0.210
G.C.	2.68	2.72	Ten. Str. (lb. per sq. in.).....	38,750	45,300
Mn.	0.67	2.80	Brinell (No.).....	196	241
Si.	1.73	1.78			

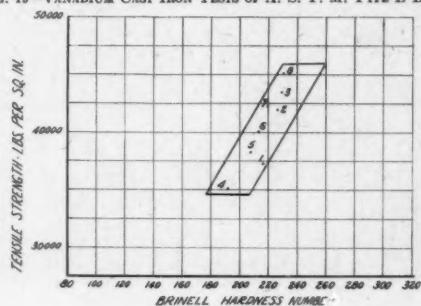
FIG. 18—ELECTRIC ROCKING PROCESS PLAIN AND HIGH MN. IRONS

FIG. 17—MANGANESE CAST IRON TESTS OF A. S. T. M. TYPE B BARS 1.30 IN. IN DIAMETER

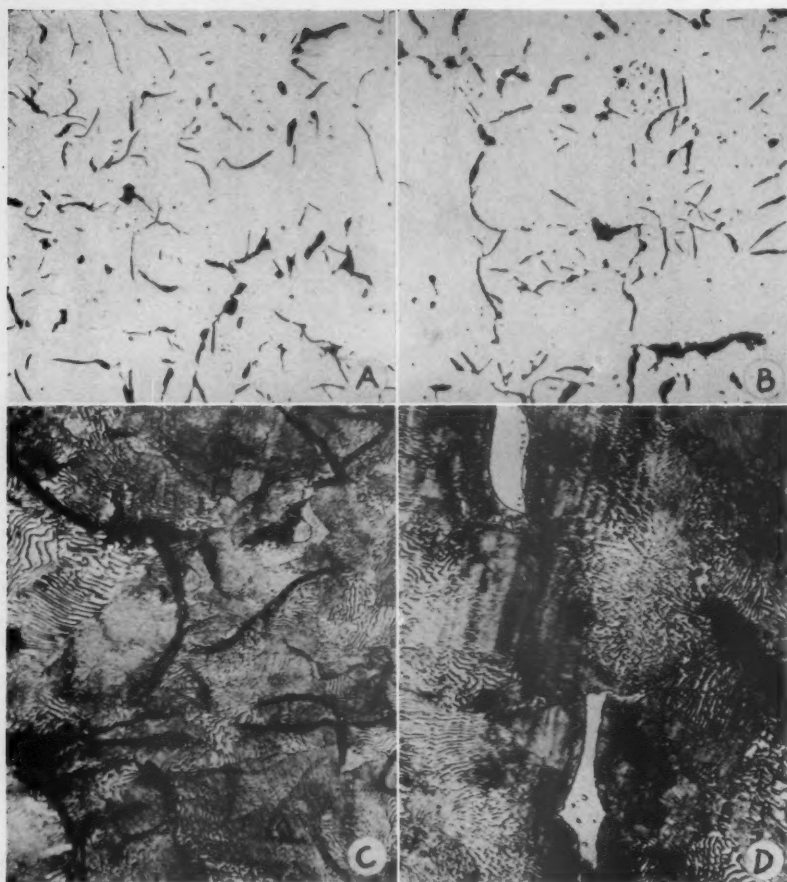


*Surls and Seifing, Michigan State College.

FIG. 19—VANADIUM CAST IRON TESTS OF A. S. T. M. TYPE B BARS.



* Climax Molybdenum Co. Other bars furnished by the Vanadium Corporation of America.



Plain Iron (A) and (C)

Vanadium Iron (B) and (D)

(A) X100 Unetched—(C) X500 Etched 2% Nital (B) X100 Unetched—(D) X500 Etched 2% Nital

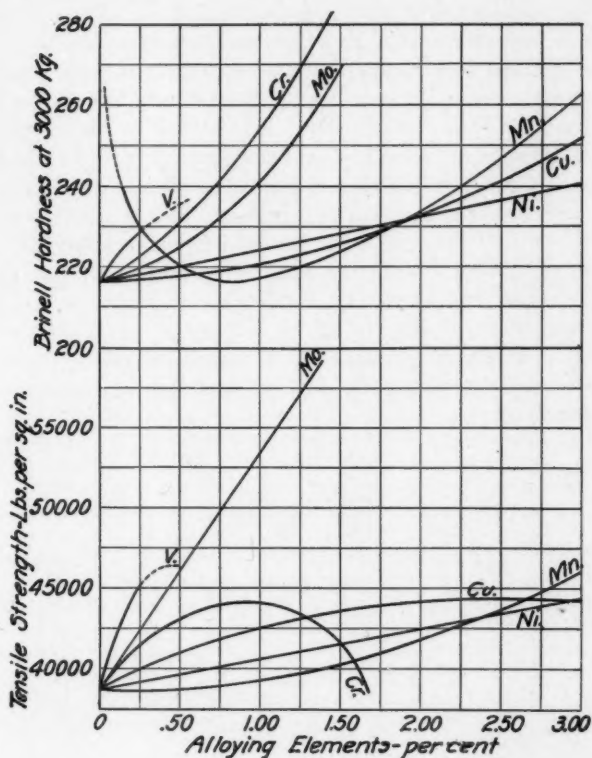
Analysis	Plain Iron %	Vanadium Iron %	Physical Properties	Plain Iron	Vanadium Iron
T.C.	3.21	3.16	Transverse (lb.).....	2,640	3,020
C.C.	0.67	0.71	Deflection (in.).....	0.250	0.280
G.C.	2.54	2.45	Ten. Str. (lb. per sq. in.).....	38,700	44,700
Mn.	0.79	0.77	Brinell (No.).....	212	228
Si.	1.89	1.91			
S.	0.08	0.08			
P.	0.17	0.16			
V.	....	0.13			

FIG. 20—ELECTRIC PROCESS PLAIN AND VANADIUM IRONS

elements. It tends to refine the graphite flakes and in general increase toughness and strength.

36. Fig. 19 shows the beneficial effects produced in strength and hardness from small additions of vanadium. The relationship between hardness and tensile strength is shown in block form covering only two base irons.

37. Fig. 20 shows the structural effects produced by an addition of vanadium. The etched photomicrographs reveal in a strik-



Composition of Base Iron

T.C. %	C.C. %	G.C. %	Mn. %	Si. %	P. %	S. %	Ten. Str. lb. per sq. in.	BHN No.
3.24	0.67	2.57	0.71	1.88	0.17	0.09	39,000	217

FIG. 21—BRINELL HARDNESS AND TENSILE STRENGTH OF A STANDARD BASE IRON (ELECTRIC MELTED) AS AFFECTED BY ADDITIONS NICKEL, CHROMIUM, MOLYBDENUM, MANGANESE, VANADIUM AND COPPER.

ing way the carbide stabilizing effect of small amounts of vanadium. The white areas are probably vanadium carbides.

SUMMARY CHART

38. It is not to be assumed that the curves shown in Fig. 21 are conclusive and that these curves are lines of expectancy for each alloying element in all cases, but rather with irons only of the base composition shown, and produced in an electric furnace where all variables such as pouring temperatures, character of the charge, etc. are kept constant for the series. It is to be expected that these curves would show up quite differently, at least in some cases, should the base iron be changed to a softer or harder variety.

39. It must be recognized that there are other factors involved in the selection of an alloying element than those listed in Fig. 21 which are tensile strength and hardness. It is not the author's desire to go into the vast detail involved in making specific selections of alloying elements for definite requirements, but rather that the reader will appreciate that each element has a very definite contribution to offer to the metallurgy of cast iron and for this reason direct comparisons of the respective value of alloying elements purely from tensile strength and hardness curves is to be discouraged.

DISCUSSION

Presiding: FRED J. WALLS, International Nickel Co., New York.

CHAIRMAN WALLS: The paper to be presented here at this time is divided into two sections and will be presented by two individuals, A. L. Boegehold, General Motors Research Laboratory and V. A. Crosby, Climax Molybdenum Co. Both sections relate to the structure and properties of cast iron. Mr. Boegehold treats plain iron, Mr. Crosby alloy irons. Mr. Boegehold will first present his section, which is entitled "Influence of Composition and Section Size on the Strength-Hardness Ratio in Cast Iron". Mr. Boegehold.

MR. BOEGEHOLD: This paper admittedly does not contain any particularly new data, but we hope we have arranged the data we have and presented them in a somewhat new fashion so that a better appreciation will be obtained of the effect of microstructure and the physical properties of the microconstituents on the hardness-strength ratio of cast iron.

CHAIRMAN WALLS: This is indeed a very fine paper as presented by Mr. Boegehold. It not only represents a great deal of work in its prepara-

tion but is an assembly of a large amount of data in such form that they are clearly understandable.

DR. JAS. T. MACKENZIE:¹ This is a very fine paper. We derive a great deal of benefit by having someone like Mr. Boegehold sum up this type of information and give us a resume of the existing information. I would like to correct one statement in the paper and that is about those bars mentioned in paragraph 22. They were not cast 1.20 in.; they were cast 1.40 in. and machined down to 1.20 in., which will make quite a little difference in values.

MR. BOEGEHOLD: I accept the correction.

MEMBER: One question about that Maurer diagram, Fig. 6. What would the effect of a change in manganese on the lines be?

MR. BOEGEHOLD: I would say that the manganese would have an influence depending on whether it caused formation of more carbide or less carbide, and that would depend on the amount of manganese. If the manganese content was below about 0.40 per cent, there would not be enough manganese to completely counteract the sulphur effect and the lines on the Maurer diagram would be thrown to the right. As manganese is increased above 0.40 per cent, more sulphur would be taken out and the zone boundary lines on the Maurer diagram would move to the left. After all the sulphur had been combined with manganese, further increase in manganese would cause the lines to move to the right again due to the formation of manganese carbides.

A. H. DIERKER:² I wish to say that undoubtedly the reason there is not more discussion on this paper is because it is so complete there isn't much we can add to it, and it is so well written that there is not much we can criticize.

G. P. PHILLIP:³ This paper, prepared by Mr. Boegehold, is quite valuable as it summarizes and correlates a large amount of data on the influence of composition and cooling rate, due to section size, on the physical properties of cast irons. Both the method of presentation and the material given are such that the paper will be of real value as a reference work on the effects of these two variables on physical properties.

CHAIRMAN WALLS: The second part of this paper will be presented by Mr. V. A. Crosby on "The Microstructure and Physical Properties of Alloy Cast Iron".

MR. CROSBY: My part of this paper is not to be understood as a symposium on the effect of alloys, but rather a few remarks about the observed effects obtained from certain alloy additions. Mr. Boegehold has summarized the plain iron data and has presented same in an admirable manner. This paper begins where his leaves off, as shown in the following block charts where strength is plotted against brinell hardness.

R. SCHNEIDEWIND⁴ and J. W. HAMILTON⁵: (*Submitted as written dis-*

¹ American Cast Iron Pipe Co., Birmingham, Ala.

² Ohio State University, Columbus, O.

³ Metallurgist, International Harvester Co., Chicago, Ill.

⁴ Research Engineer, University of Michigan, Ann Arbor, Mich.

⁵ Research Department, Vanadium Corporation of America, New York, N. Y.

cussion) This presentation on alloyed cast irons is most interesting and represents what must have been a large amount of work. It should be helpful as a guide in selecting compositions for specific applications.

The values given on vanadium irons of Fig. 19 were obtained at the laboratories of the University of Michigan. Photomicrograph D (Fig. 20) of a 0.13 per cent vanadium iron shows two large white areas which the author in oral presentation identified as carbides. These are probably phosphide eutectic since in our work on four series of irons of different base compositions and varying vanadium concentrations from 0 to 0.35 per cent, in no case was any more than a trace of free carbides present.

We present photomicrographs 1 to 4 of Fig. 22 showing typical sections of a series of irons containing from 0 to 0.35 per cent vanadium content at 1000 diameters, etched. In the higher concentration vanadium tends to sorbitize the matrix. Photomicrographs 5 to 8 of Fig. 23 show the same irons unetched at 100 diameters. The plain iron shows some eutectic graphite which is corrected to form flake graphite of small size by the vanadium.

Vanadium as an alloying addition serves two purposes; first, to refine the graphite structure and decrease the particle size, and second, to produce hardening. When used in combination with nickel and molybdenum, it promotes greater uniformity from heat to heat and also reduces the sensitivity of the iron to section size.

Best results in small electric furnace melting have been obtained not by ladle addition but by adding to the furnace about 30 seconds before pouring. Additions to small ladles prove to be less consistent in effect and do not bring out the full value of this alloy.

We have no data at present for additions above 0.35 per cent vanadium and, therefore, cannot comment on the dotted extrapolated portion of the curves of Fig. 21. Indications are that the hardness curve should have about the same type of curvature as have those of chromium and molybdenum. There are no data to support the bending over of the tensile strength curve in the case of vanadium irons.

GEO. F. COMSTOCK*: (*Submitted as written discussion*) This informative and excellently presented paper was much enjoyed by the writer, who hopes that in spite of the minor criticisms which are made in this discussion he will not seem to fail in appreciation of the author's valuable contribution.

It is, of course, somewhat disappointing to one who has specialized in the metallurgical applications of titanium to find in this paper no data on this alloying element, in spite of the large amount now being used in cast iron. The chief excuse for this discussion is to correct this omission by supplying some results obtained with titanium, in a form as closely similar as possible to that used by the author for other alloys.

In paragraph 3 of the paper, titanium is classed below silicon in graphitizing effectiveness, but when one stops to consider that titanium is effective as a graphitizer when the content of titanium in the iron is increased by only 0.1 per cent, and 0.25 per cent is probably the most ever

* Metallurgist, The Titanium Alloy Manufacturing Co., Niagara Falls, N. Y.

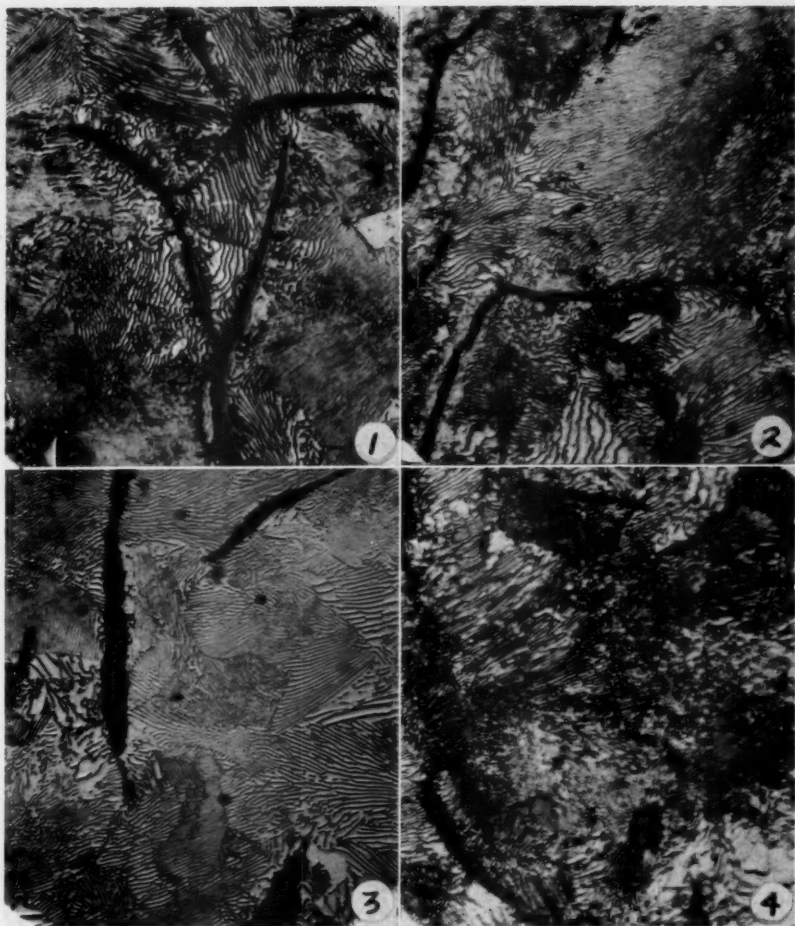


FIG. 22—TYPICAL SECTIONS OF AN IRON WITH INCREASING VANADIUM CONTENT.
BASE ANALYSIS, CARBON 3.10 PER CENT; SILICON 2.00 PER CENT, MANGANESE 0.70
PER CENT.

MICROGRAPH 1, 0.0 PER CENT VANADIUM;
MICROGRAPH 2, 0.1 PER CENT VANADIUM;
MICROGRAPH 3, 0.20 PER CENT VANADIUM;
MICROGRAPH 4, 0.35 PER CENT VANADIUM.

ALL MICROGRAPHS 1000 DIAMETERS, ETCHED WITH 3 PER CENT NITAL.

used in commercial cast iron, while differences in silicon content of 0.1 or 0.2 per cent are considered entirely negligible and within the experimental error, it seems obvious that titanium is actually above silicon in graphitizing effectiveness, though, of course, not so widely used.

A few other points which on studying the paper seem to need clearing

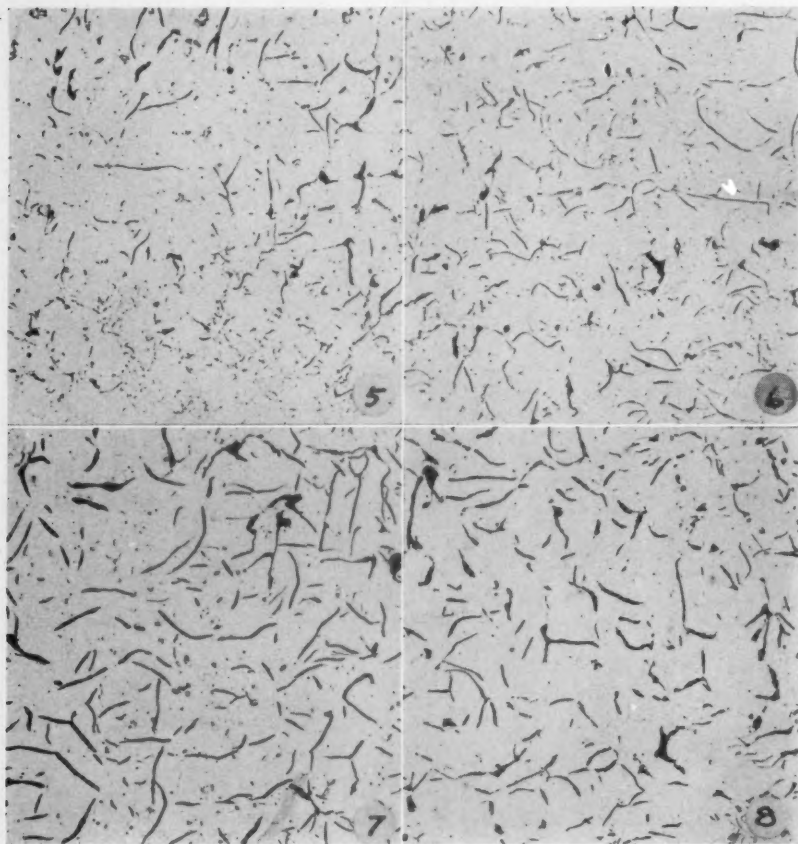


FIG. 23—TYPICAL SECTIONS OF AN IRON WITH INCREASING VANADIUM CONTENT. BASE ANALYSIS, CARBON 3.10 PER CENT, SILICON 2.00 PER CENT, MANGANESE 0.70 PER CENT.

MICROGRAPH 5, 0.0 PER CENT VANADIUM;
MICROGRAPH 6, 0.1 PER CENT VANADIUM;
MICROGRAPH 7, 0.2 PER CENT VANADIUM;
MICROGRAPH 8, 0.35 PER CENT VANADIUM.
ALL MICROGRAPHS 100 DIAMETERS, UNETCHED.

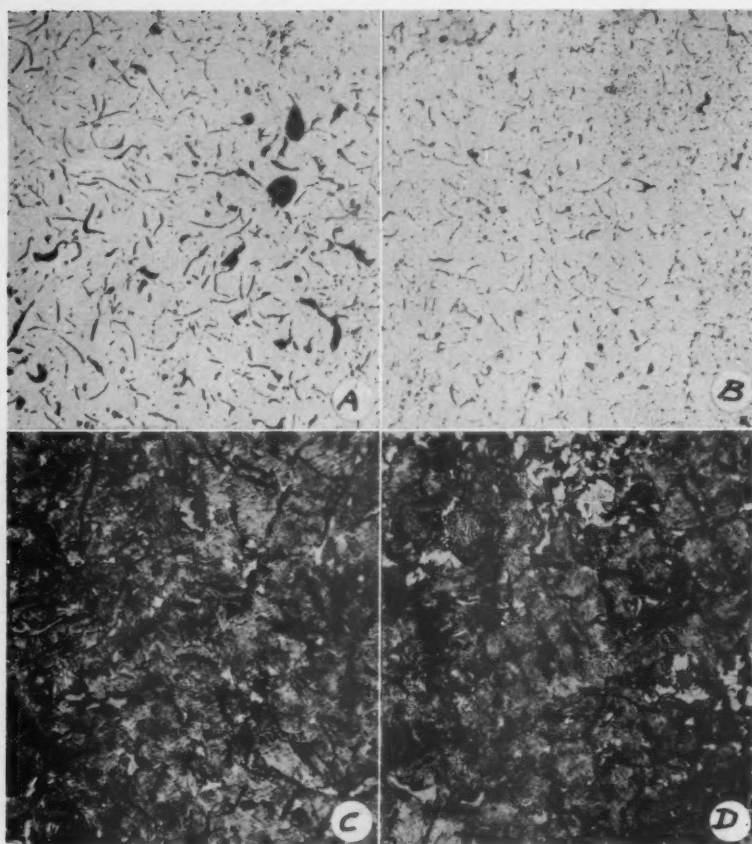
up are, first, the reason for drawing the nickel diagram, Fig. 2, as shown. Why were the points, 5, 6 and 7 given such prominence in determining the shape of the diagram, when with the melting process not given, the reason for the abnormally high strength remains a mystery? In view of the results from bars 4 and 9, it does not seem that low carbon content can be the full explanation for these high strengths, and they do not seem to agree with general experience in the use of nickel in cast iron, as shown by the author's own curve in Fig. 21.

Titanium is an element that occurs to some extent in all pig iron, and in all samples of cast iron that have ever been analyzed in the laboratory where the writer is employed. Often there is more titanium than sulphur in a cast iron to which titanium was not added intentionally, although sulphur, of course, is much more commonly determined by chemical analysis. The amount generally present in ordinary cast iron is below about 0.05 per cent, while the characteristics of titanium alloy cast iron are shown when additional titanium is added to bring the content above 0.08 to 0.1 per cent.

Titanium added in this way is a graphitizer which promotes graphite formation in very fine particles rather than in the usual coarser flakes. By this change in graphite form, the strength, hardness and machinability are usually increased. Owing to the graphitizing effect of titanium, it tends to produce ferrite in the microstructure, and in high silicon irons the strength may, therefore, not be improved by titanium. Since its strengthening action is due to decreasing the graphite particle size, this is not prominent in high carbon irons. Titanium gives interesting results when used with chromium, since chromium counteracts the ferrite-forming tendency of titanium, and titanium decreases the tendency of chromium to produce white iron at thin sections and corners. Both alloys improve the strength in different ways.

Fig. 24, presented by the writer, shows the structure, composition, and properties of a pair of cast irons poured from the same rocking electric furnace heat, one of them having received an addition of ferro carbon titanium, low in silicon content. This shows that the results obtained with titanium in cast iron are not due to silicon added with the titanium, as has been suggested. In Fig. 25 the same comparison is shown for a pair of cupola-melted irons, one of which was treated with chromium and foundry ferro-titanium (low carbon, high silicon). It should be noted that these are high carbon irons. Fig. 26 comprises a diagram and table of test results of chromium-titanium irons, the form and arrangement being copied from those used in the paper. The results on the electric-melted heats 7 to 12 inclusive, were taken from the writer's A. F. A. paper* on titanium alloy cast iron, presented in 1933. It will be noted that although all the crucible-melted irons, and some of the others in Fig. 26 are higher in carbon than any in Fig. 7, the general range of strength values is somewhat higher for the chromium-titanium irons. Our results from chromium cast iron, without titanium additions, with carbon as high as in the crucible melts in Fig. 26 were decidedly lower than those shown in Fig. 7 for lower carbon irons.

* Results of Comparative Tests of Titanium Treated and Other Alloy Cast Irons, Transactions, A.F.A. vol. 41 (1933) pp. 278-285.



Plain Iron (A and C)

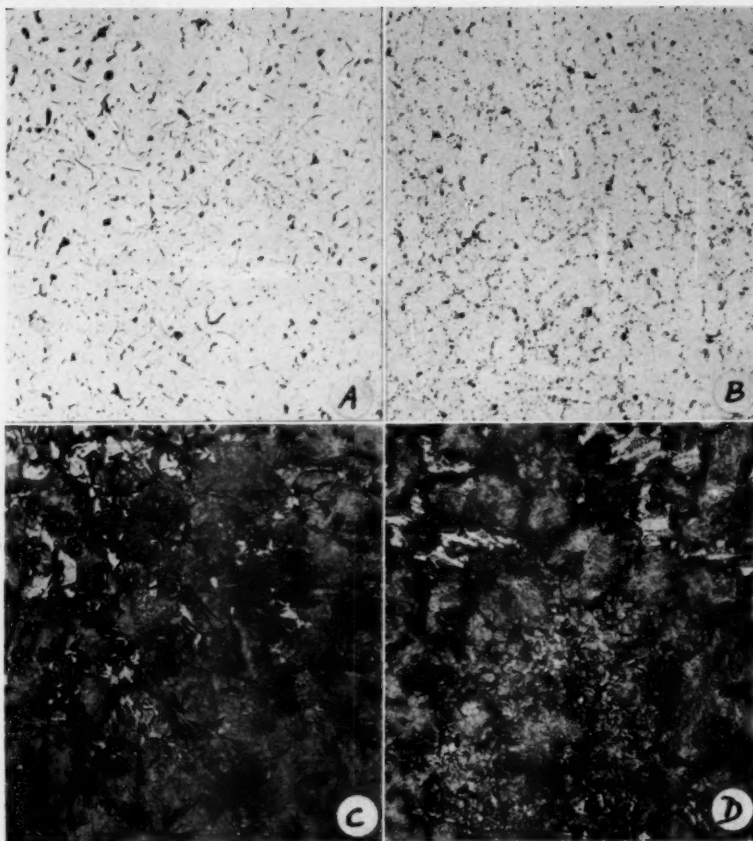
Titanium Iron (B and D)

(A) and (B) X 50, Unetched

(C) and (D) X100, Etched, Picric Acid.

Analysis	Plain Iron %	Titanium Iron %	Physical Properties	Plain Iron	Titanium Iron
T.C.	3.00	3.14	Transverse (12 in. Span) (lbs.).....	4,030	5,220
C.C.	0.55	0.56	Deflection (12 in. Span) (in.).....	0.125	0.180
G.C	2.54	2.58	Tensile (lbs. per sq. in.).....	33,850	40,000
Si.	2.17	2.21	Brinell (No.).....	190	196
Ti.	0.053	0.156			

FIG. 24—ROCKING ELECTRIC PROCESS PLAIN AND TITANIUM IRONS

**Plain Iron (A and C)****Cr-Ti Iron (B and D)**

(A) and (B) X 50, Unetched

(C) and (D) X200, Etched, Picric Acid

Analysis	Plain Iron %	Cr-Ti Iron %	Physical Properties	Plain Iron	Cr-Ti Iron
T.C.	3.58	3.57	Transverse (18 in. Span) (lbs.).....	2,620	2,760
C.C.	0.53	0.63	Deflection (18 in. Span) (in.).....	0.28	0.22 (flaw)
G.C.	3.05	2.94	Tensile (lbs. per sq. in.).....	30,600	34,300
Si.	1.91	2.00	Brinell (No.).....	187	217
Cr.	—	0.48			
Ti.	0.045	0.138			

FIG. 25—CUPOLA PROCESS PLAIN AND CHROMIUM-TITANIUM IRONS

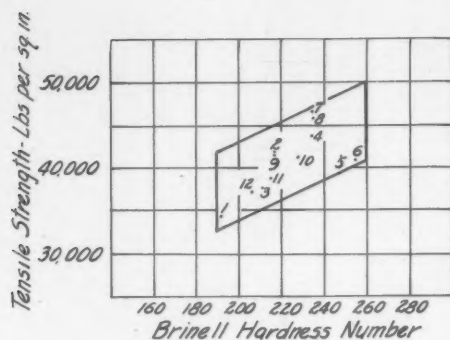


FIG. 26—CHROMIUM-TITANIUM CAST IRON TESTS ON BARS CAST 1.25 IN. ROUND AND MACHINED TO 0.8 IN. DIAMETER

The photomicrographs which are available for this discussion were not taken at the same magnification as the author's, since in our metallographic work on cast iron we have found it entirely too difficult, if not impossible, to choose a truly typical spot on a polished surface at as high a magnification as 100 to represent the average graphite form, or on an etched surface at as high a magnification as 500 to represent the average structure. At these high magnifications there is more difference between different spots of the same specimen than there is between the different specimens of cast iron in general, since the normal microstructure of cast iron varies so widely on a comparatively coarse scale. The author has done well to illustrate the acicular pearlite in high molybdenum irons at 500 diameters, but otherwise the magnification adopted for Fig. 5 seems preferable.

J. S. VANICK[†]: I would like to state at this time that irons 5, 6 and 7 reported in table of Fig. 2 were cupola melted mixtures processed at the spout with additions of ferro-silicon and nickel conforming in this detail to the practice described in a paper before the A. F. A. in 1929 entitled "High Strength Cast Iron" by F. B. Coyle and D. M. Houston.

[†] International Nickel Co., New York City.

DR. MACKENZIE: Mr. Crosby, how did you get that manganese down to 0.25 when the base metal had 0.71 in it?

MR. CROSBY: While it is true that the base metal for the curves plotted in Fig. 21 shows a manganese content of 0.71, it is quite obvious in plotting a manganese curve that the manganese would have to vary somewhat in order to ascertain the effect of manganese in a given carbon, silicon, sulphur, phosphorus iron. Therefore, one might say that the base iron mentioned in Fig. 21 holds for all alloys mentioned except manganese, and in the case of the manganese curve the carbon, silicon, sulphur and phosphorus were held as per the data shown in Fig. 21.

CHAIRMAN WALLS: I think that manganese curve agrees very well with the curve recently published by Boyles in his paper before the February, 1937, meeting of the A. I. M. E.

C. O. BURGESS*: Mr. Boegehold and Mr. Crosby deserve our thanks for their able presentations. In regard to the effect of chromium on hardness, we have made tests in which up to 0.75 per cent of this element was added to both copper and nickel base irons, and I hope these data will shortly be available in a publication of the American Foundrymen's Association. It was interesting to find that starting with copper and nickel base irons of about 230 Brinell, a hardness increases of only 10 points Brinell accompanied additions of 0.25 to 0.35 per cent chromium, and no appreciable further change in hardness was evident with an increase to 0.50-0.55 per cent chromium.

The base irons were made in a high frequency furnace using a mixture consisting of 20 per cent steel and 80 per cent pig iron.

G. P. PHILLIPS: This paper, prepared by Mr. Crosby, gives us an impartial review of the effects of alloying elements on the structures and physical properties of cast irons.

The set of curves given in Fig. 21 on effects of various alloying elements on the hardness and tensile strength of a type of base iron largely employed in automotive castings is particularly valuable. The data given represent a large amount of work that has been well summarized in this chart. It is to be hoped that similar sets of curves will become available for other types of base irons and for other physical properties in the future.

P. S. LANE†: Mr. Crosby, referring to iron of Fig. 10 that was cast in the light section, just how is the machinability on this iron as compared to the type that is normally cast in this size section? Also, is it particularly sensitive to temperature variations, for instance, in pouring?

MR. CROSBY: The iron shown in Fig. 10, to which Mr. Lane refers, was cast in an $\frac{1}{8}$ in. section being initially a piston ring iron. I am advised that rings cast of the composition mentioned in Fig. 10 are not machinable as cast and that a particular heat treatment resulting in a final hardness of Rockwell "C" 25 to 30 is performed to obtain the necessary machinability. The interesting point in this connection is the fact

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that the acicular pearlite or pseudo-martensite is retained after the treatment. This structure is supposed to have marvelous wear resistant properties and has been termed the "anti-scuff ring."

F. J. O'NEILL¹⁰: I would like to make a comment on the hardness curve of Fig. 21, comparing nickel and copper. We have not plotted any curves in that respect, but when we made tests on irons of up around 1.50 per cent copper, we ran into considerable machining difficulty; the iron apparently got very tough. I do not know whether that is generally the case or not. Our iron had some chromium in it, about 0.25 or 0.30 per cent, in the $\frac{1}{4}$ in. section. This would probably not hold with heavier sections.

MR. CROSBY: Did you take any Brinell readings to ascertain the actual hardness?

MR. O'NEILL: I do not recollect what they were, but they were not excessive. The iron was entirely pearlitic.

MR. CROSBY: It is possible that you had a somewhat stronger and tougher structure and that the metal was a little harder to remove in cutting. We have not found that copper increases the hardness appreciably below 1.0 per cent. Our experience on copper is comparatively limited.

¹⁰ Western Foundry Co., Chicago, Ill.

A Correlation of the Physical and Chemical Properties of Clays With the Durability of Molding Sands

By C. E. SCHUBERT,* Urbana, Ill.

Abstract

The basis of the author's study was a comparison of the three suggested methods for determining durability, namely, the mold test, the oven test and the hydration and re-hydration methods. The author describes the various tests and the equipment used and gives the results obtained for green permeability, green compression, dry permeability and dry compression, clay content and fineness tests. The mineralogy and chemistry of the bonding substances also were investigated. The various constituents of the clays were determined petrographically and their effects determined. Information also is given on their properties and base-exchange capacities are discussed. Results of the investigation show that it is not possible to predict the life of molding sands by any of the three methods and that it is more economical for foundrymen to add bond after the sand has been used for a number of heats rather than to hold the strength constant by frequent additions of bond. Further conclusions include the fact that durability depends on the physical and chemical properties of the mineral or minerals in the bond.

INTRODUCTION

1. Three general methods have been tried by previous investigators in an attempt to determine the durability of molding sands: (1) the mold test method, (2) the oven test method, (3) the hydration and dehydration method. The first mentioned method is long and time-consuming, while the last two methods are shorter, but are generally believed to be less accurate.

2. Since, from the standpoint of foundrymen, it is desirable to have available a short method of testing molding sands for durability, it was suggested by the A.F.A. that a few selected molding sands should be tested by all three methods, and a study made for the purpose of correlating the results obtained. In response to

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this suggestion, tests were concluded on various molding sands, two of which were natural sands, while others were synthetic molding sands. The sand samples were furnished by members of the A.F.A. Committee on Durability of Molding Sands and Harry W. Dietert, the latter also supplying part of the sand testing equipment.

APPARATUS AND METHODS

3. The apparatus used in the investigation was that which conformed to A.F.A. standards for the performance of such tests as clay and fineness, green permeability, compression, dry permeability, and compression tests. Much additional apparatus also was used, such as an electric furnace to heat the sands, a number of steel cylinder boiler tubes to make the molds, a cylindrical wooden pattern, a crucible-type high-pressure gas furnace to melt the cast iron, an optical pyrometer to take temperatures of molten metal, potentiometer and thermocouples, a number of glass bottles equipped with rubber stoppers to temper the sands, and a muller type sand mixer to mix the sands.

General Method of Procedure

4. Two natural and two synthetic sands were used in the investigation; namely, Albany, Mulberry Grove, synthetic bentonite, and synthetic Ohio clay sands. Two additional synthetic sands were also used called "constant bentonite" and "constant Ohio clay bond" because after the sands were tempered, the green compression strengths were to be held constant throughout the investigation. The respective optimum moisture contents were: 6.5 per cent for the Albany, 7.5 per cent for the Mulberry Grove, and 5 per cent for both the bentonite and the Ohio clay sand.¹ The sands were placed in rubber stoppered glass bottles and allowed to temper for at least 12 hours. Enough sand was prepared for the three methods to be investigated. Original clay and fineness, green permeability, and compression tests were performed on the sands after tempering.

5. *Mold Test*—The mold test method was the first test investigated and consisted in preparing suitable molds in the steel cylinders by means of the cylindrical pattern and covering them with sprue covers until the metal which had been previously heated in the crucible was ready to pour. Pouring temperatures were

¹ Minutes of meeting of Subcommittee on Life of Sands and Clays of A.F.A. Foundry Sand Committee, March 23, 1929, Detroit, Michigan.

recorded at the time of pouring. After the molds were poured, they were left to stand over night before shaking the castings out and carefully recovering the molding sand. The molding sands were tempered to their respective moisture contents and allowed to stand over night before performing the various tests.

6. This cycle of tempering, testing, melting cast iron, preparing molds, pouring the metal, recovering sand and retempering was repeated until the sand had been used ten times. After the tenth time, the sands were recovered as before and the clay and fineness test was performed on them before tempering. After tempering, the various tests were performed and the two synthetic sands were adjusted to their original green compression strength by the addition of clay bond. The amount of clay necessary to bring the synthetic sands back to their original green compression strengths was recorded.

7. *Oven Test*—The next test performed was the oven test which consisted in placing the previously tempered portions of each molding sand in a porcelain-covered iron container and subjecting them to a temperature of 800° F. for 2 hours in the electric furnace. After the sand cooled to room temperature, each sand was adjusted to its respective optimum moisture content and set aside for tempering. After tempering, the various tests were performed.

8. This heating, tempering, and testing was repeated at 200° intervals until 1400° F. had been reached. After heating to 1400° F., the sands were weighed and the total loss in weight obtained. Clay and fineness tests were performed on each sand and enough clay was added to the synthetic sands to restore them to their original green strength.

9. *Hydration and Dehydration Test*—The last method investigated was the hydration and dehydration method. The prepared samples were placed in an electric oven and heated at 225° F. for 4 hours. They were removed from the oven, allowed to cool to room temperature, and weighed to determine losses or gains in weight.

10. The sands were placed in porcelain covered iron containers and heated at a temperature of 800° F. for 1 hour in the electric furnace. They were allowed to cool to room temperature and losses in weight due to dehydration at 800° F. were recorded. After this the sands were tempered to their respective optimum moisture contents and the various tests performed.

11. This cycle was repeated at 200° intervals until the sand had been heated to 1400° F. After this heating, the sands were allowed to cool to room temperature and the final weights of the sands recorded. The clay and fineness tests were performed on all the sands and the two synthetic sands were adjusted with clay bond to their original green compression strength.

RESULTS OF PHYSICAL TESTS

Results of Green Permeability Tests

The results of the green permeability tests of all the sands are shown in Fig. 1 and Table 1. The original green permeability of the Mulberry Grove Sand was much higher than that of all the other sands, although the clay content was much greater than of the other sands. The fineness test showed this sand to have the lowest fineness number and therefore, would be largest in particle size, which in turn, would produce a high green permeability.

13. The permeability of the Albany Sand increased quite uniformly in the mold test method from 22.4 to 55. In the oven

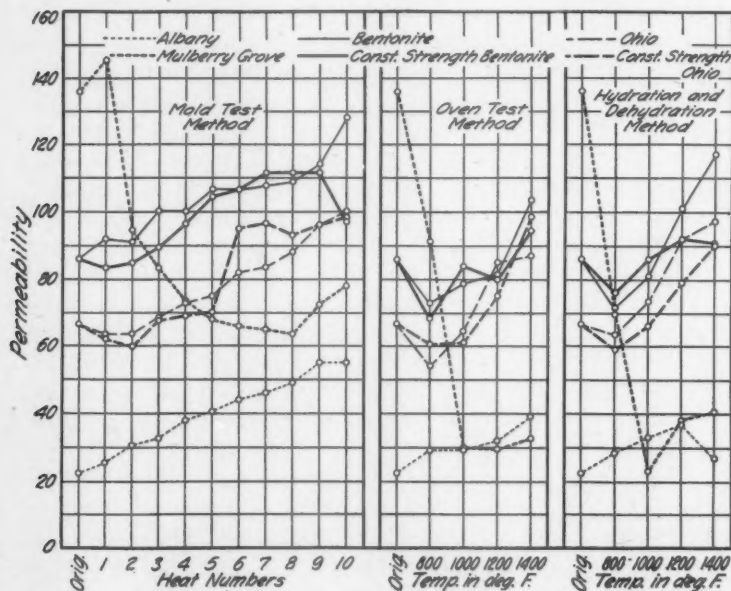


FIG. 1—RESULTS OF GREEN PERMEABILITY TESTS.

TABLE 1
RESULTS OF GREEN PERMEABILITY TESTS

	Type of Molding Sand					
	Albany	Mulberry Grove	Bentonite	Constant-Strength Bentonite	Ohio	Constant-Strength Ohio
	Permeability					
Mold Test Method						
Original value.....	22.4	136.0	86.0	86.0	66.7	66.7
Value after						
1st heat.....	25.5	145.5	92.0	83.5	63.4	62.0
2nd heat.....	30.5	94.5	91.1	84.9	63.5	59.6
3rd heat.....	32.5	83.3	100.2	89.5	68.6	67.7
4th heat.....	38.0	73.5	100.0	96.4	73.0	69.0
5th heat.....	40.5	68.0	106.6	104.4	75.0	70.1
6th heat.....	44.0	66.0	106.6	106.6	82.1	95.0
7th heat.....	46.0	65.0	107.7	111.3	83.5	96.4
8th heat.....	49.0	63.5	108.9	111.3	88.0	92.0
9th heat.....	55.0	72.5	114.0	111.3	96.0	96.0
10th heat.....	55.0	78.0	128.0	97.0	100.0	98.3
				97.0		90.0
Oven Test Method						
Original value.....	22.4	136.0	86.0	86.0	66.7	66.7
Value after						
800 deg. F.....	29.0	91.1	73.0	68.5	54.0	60.4
1000 deg. F.....	29.2	30.0	78.9	84.0	64.6	61.0
1200 deg. F.....	32.0	29.5	81.4	80.0	85.0	75.0
1400 deg. F.....	39.0	32.5	103.3	94.5	87.0	98.5
Hydration and Dehydration Method						
Original value.....	22.4	136.0	86.0	86.0	66.7	66.7
Value after						
800 deg. F.....	28.2	69.6	71.6	76.0	63.4	59.0
1000 deg. F.....	32.9	23.0	81.0	86.0	73.5	66.0
1260 deg. F.....	36.8	38.0	101.0	92.0	92.0	79.0
1400 deg. F.....	27.0	40.5	117.0	90.5	97.1	90.0

test and hydration and dehydration methods, the permeability increased at a slower rate, and the final permeability in these two methods was much lower than in the mold test method.

14. The permeability curves of the bentonite and "constant strength bentonite" are nearly identical in each method except in the case of the final permeability of the "constant strength bentonite" sand. This is due, no doubt, to the adding of clay to the "constant strength bentonite" sand to maintain (Table 2) the green compression strength as nearly constant as possible. The final permeability of the Ohio sand in the mold test method was

100 while the "constant strength Ohio" sand was 98.3. Clay added to this sand during the tests did not seem to have any great effect upon the permeability. Clay was added to this sand during the oven test and the hydration and dehydration methods.

15. The final permeabilities of all the sands in the mold test method were greater than the final permeabilities in the oven test and hydration and dehydration methods, respectively. This was because of the nature of the tests. The mold test method was a method which not only applied heat to the bonding materials in the sand, but the hot metal came in direct contact with the sand thus causing the removal of some of the clay bonding material from the sands. In the other two methods, the bonding material was subjected to heat alone and any change in the bonding material which would produce a higher permeability was caused by the dehydration of this material.

Results of Green Compression Tests

16. The green compression strength of the Mulberry Grove Sand (Fig. 2, Table 2) decreased rapidly from the original strength of 16 lb. per sq. in. to 2.5 lb. per sq. in. in the mold tests, 3.7 lb. per sq. in. in the oven tests, and 2.8 lb. per sq. in. in the hydration and dehydration tests. The original strength of 16 lb. per sq. in. was no doubt due to the high clay content of 28.4 per cent.

17. The green compression strength of the Albany sand decreased quite uniformly during the mold tests and the hydration and dehydration tests.

18. From Fig. 2, it can be seen that the green compression strength of the bentonite sand decreased quite uniformly during the mold tests while during the oven tests and hydration and dehydration tests, the strength decreased slowly after the first three tests, but rapidly to approximately 1 lb. per sq. in. after the final heating to 1400° F.

19. By adding a total of 225 gms. of clay in small amounts during the three tests, the green compression strength of the constant strength bentonite sand was kept as nearly constant as possible.

20. During the mold tests, the compression strength of the Ohio sand first increased during all of the tests, then gradually decreased. In the mold tests, the compression strength gradually decreased to 2.25 lb. per sq. in. from 4.30 lb. per sq. in. In the

other two tests, the compression strength, after heating to 1400° F. was equal to the original 4.3 lb. per sq. in. which showed that some change was taking place to the clay bond material. In the mold test, the metal coming in contact with the clay bond would account for a lower compression strength at the end of the tenth test. In the

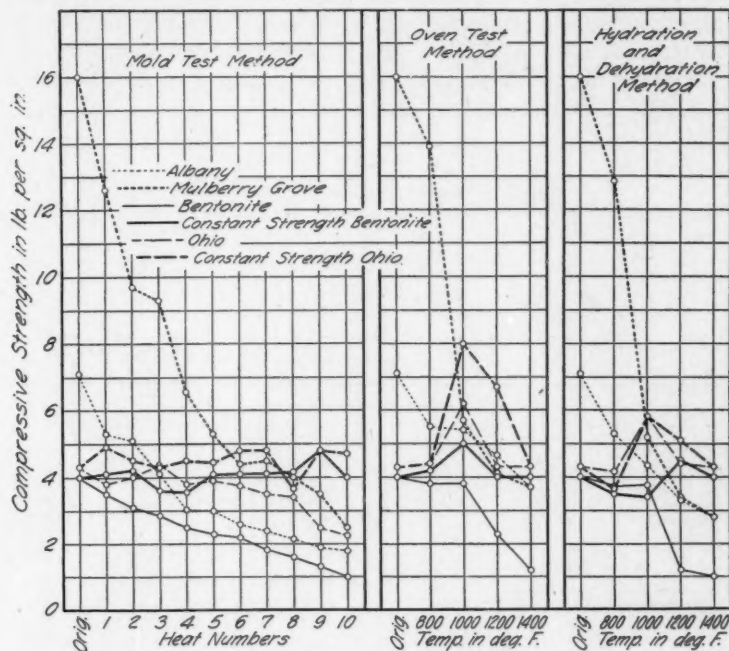


FIG. 2—RESULTS OF GREEN COMPRESSION TESTS.

oven test and dehydration test, there was no contact of metal with the clay bond. This irregularity with the Ohio clay bond in contrast to the bentonite clay bond seemed to need some further investigations in order to explain this phenomena. Later, in the investigation, the reason for this increase in strength was satisfactorily explained.

Results of the Dry Permeability Tests

21. Fig. 3, Table 3 show the results of the dry permeability tests. In the three tests, most of the sand increased in dry permeability from their original dry permeabilities. The Mulberry

Grove sand was an exception. It is true that some of the sands lost in dry permeabilities at first, and then gradually increased, but they did not fluctuate to such a great degree. Some trouble was encountered in performing the dry permeability test on the Mulberry Grove sand. While baking this sand at 225° F., the sand contracted, so that it pulled away from the sides of the tube and the specimen would fall out of the tube. The bentonite sand in the oven test method lost in dry permeability at first, and at the end of the test had a lower dry permeability than its original. Likewise, the "constant bentonite" sand in both the oven test and

TABLE 2
RESULTS OF GREEN COMPRESSION TESTS

	Type of Molding Sand					
	Albany	Mulberry Grove	Bentonite	Constant-Strength Bentonite	Ohio	Constant-Strength Ohio
	Compression Strength in lb. per sq. in.					
Mold Test Method						
Original value.	7.1	16.0	4.0	4.0	4.3	4.3
Value after						
1st heat.	5.3	12.6	3.5	4.1	3.8	4.9
2nd heat.	5.1	9.7	3.1	4.2	4.0	4.5
3rd heat.	4.1	9.3	2.85	3.6	4.35	4.3
4th heat.	3.03	6.55	2.5	3.55	3.8	4.5
5th heat.	3.0	5.3	2.3	4.1	3.9	4.45
6th heat.	2.6	4.4	2.2	4.1	3.75	4.8
7th heat.	2.4	4.5	1.81	4.1	3.5	4.8
8th heat.	2.15	4.0	1.6	4.15	3.4	3.65
9th heat.	1.9	3.5	1.3	4.8	2.5	4.8
10th heat.	1.8	2.5	1.0	4.0	2.25	4.7
				4.0		4.3
Oven Test Method						
Original value.	7.1	16.0	4.0	4.0	4.3	4.3
Value after						
800 deg. F.	5.5	13.9	3.8	4.2	4.4	4.4
1000 deg. F.	5.4	5.7	3.8	5.0	6.2	8.0
1200 deg. F.	4.65	4.1	2.3	4.0	4.3	6.7
1400 deg. F.	3.7	3.7	1.2	4.0	4.3	4.3
Hydration and Dehydration Method						
Original value.	7.1	16.0	4.0	4.0	4.3	4.3
Value after						
800 deg. F.	5.3	12.85	3.7	3.5	4.15	3.65
1000 deg. F.	4.35	5.20	3.75	3.4	5.8	5.8
1200 deg. F.	3.3	3.4	1.2	4.5	4.4	5.1
1400 deg. F.	2.8	2.8	1.0	4.0	4.3	4.3

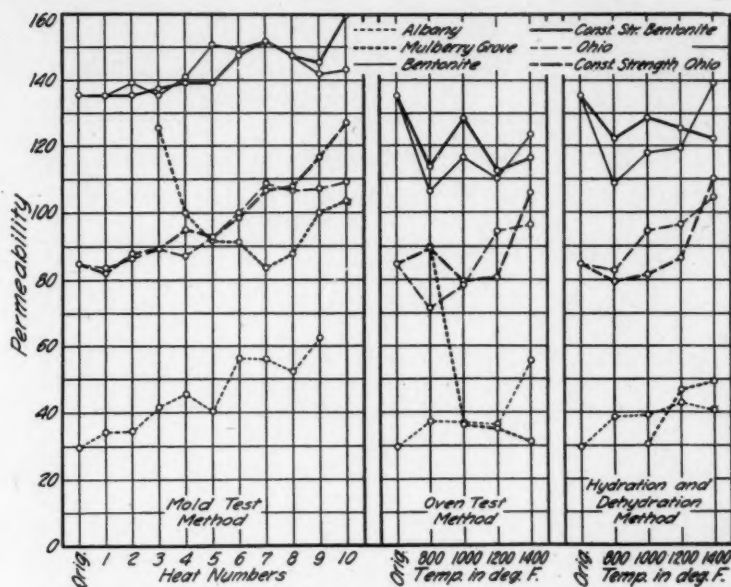


FIG. 3—RESULTS OF DRY PERMEABILITY TESTS.

the hydration and dehydration test gradually decreased in dry permeability values and at the end of the test had values lower than the original.

Results of the Dry Compression Tests

22. The dry compression strengths of all the sands decreased from their original strengths throughout all of the tests. The two constant strength sands decreased in dry compression strength even though their green compression strength was held constant. The "constant Ohio" sand decreased to a lower figure than the "constant bentonite" sand. Test results are shown in Fig. 4 and Table 4.

Results of the Clay and Fineness Tests

23. Table 5 shows the results of the fineness tests of the original sands. The fineness numbers were calculated in accordance with the standard method of the A.F.A. The distribution numbers were calculated in accordance with the method originated by Clarence E. Jackson.²

² Jackson, C. E., "A Grain Distribution Index for Sand Grading," TRANSACTIONS A., 1931, vol. 39, pp. 506-512.

TABLE 3
RESULTS OF DRY PERMEABILITY TESTS

	Type of Molding Sand					
	Albany	Mulberry Grove	Bentonite	Constant-Strength Bentonite	Ohio	Constant-Strength Ohio
	Permeability					
Mold Test Method						
Original value.....	29.7	Fell out	135.4	135.4	84.9	84.9
Value after						
1st heat.....	34.1	Fell out	135.4	135.4	83.5	82.0
2nd heat.....	34.5	Fell out	139.2	135.4	86.4	87.9
3rd heat.....	41.7	125.3	135.4	137.3	89.5	89.5
4th heat.....	45.4	100.0	141.1	139.2	87.1	95.0
5th heat.....	40.4	91.9	151.8	139.2	92.0	92.8
6th heat.....	56.3	91.2	149.3	147.3	100.0	98.2
7th heat.....	56.0	83.5	151.9	151.8	108.7	106.6
8th heat.....	52.2	87.9	147.4	147.3	106.6	107.7
9th heat.....	62.6	100.0	142.0	145.4	107.0	116.5
10th heat.....	Fell out	103.3	143.2	159.7	109.0	127.0
				143.0		100.0
Oven Test Method						
Original value.....	29.7	Fell out	135.4	135.4	84.9	84.9
Value after						
800 deg. F.....	37.1	90.0	106.6	113.9	71.6	89.5
1000 deg. F.....	36.8	36.3	116.5	128.5	78.3	79.5
1200 deg. F.....	36.3	35.0	110.2	112.6	94.5	80.8
1400 deg. F.....	55.7	31.3	123.7	116.3	96.3	106.0
Hydration and Dehydration Method						
Original value.....	29.7	Fell out	135.4	135.4	84.9	84.5
Value after						
800 deg. F.....	38.5	Fell out	108.9	122.3	87.9	79.5
1000 deg. F.....	39.1	30.5	117.9	128.5	94.5	81.4
1200 deg. F.....	42.8	46.7	119.3	125.3	96.4	86.4
1400 deg. F.....	40.4	49.1	139.2	122.2	104.6	110.2

24. It is theoretically possible for two molding sands to have the same average grain size, but to be distributed upon different screens in such a manner that the permeability and compression strengths will not be the same, although the amounts and kinds of clay in both sands are identical.

25. Theoretically, the higher the numerical value of the distribution number, the lower will be the permeability and the higher the green compression strength of the sand. In accordance with this theory, it should be noted that the Mulberry Grove molding sand had the highest green compression strength and the high-

est permeability of any of the sands tested. The large amount of clay produced the bonding strength while the distribution of the sand grains produced the high permeability. The other sands tested showed them to be in accordance with this theory.

Clay Additions and Sand Losses

26. Table 6 shows the sand losses for the three test methods,

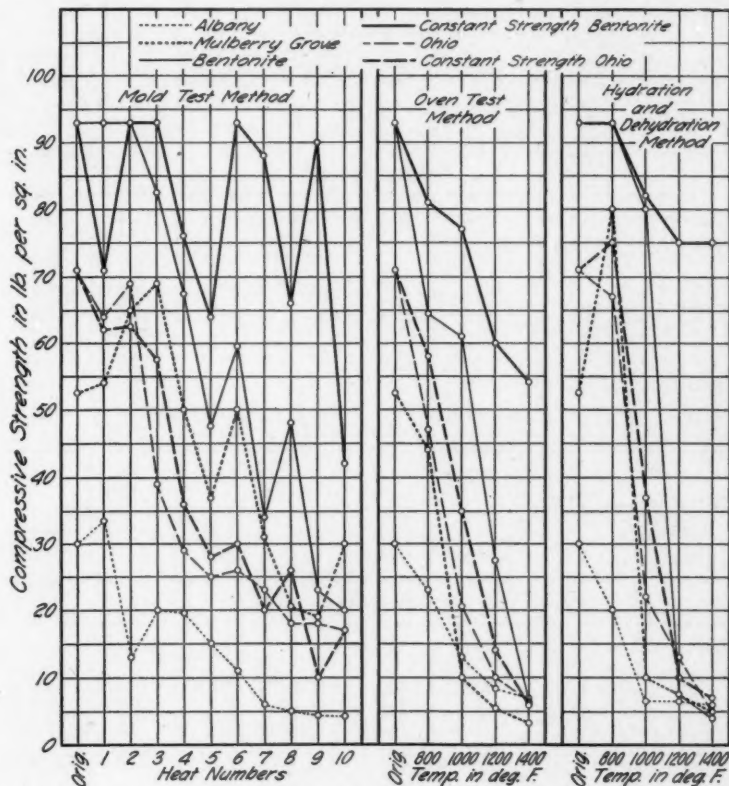


FIG. 4—RESULTS OF DRY COMPRESSION TESTS.

and the weight of the clay added to the synthetic sands. It should be noted that the clay and sand losses in the mold test were much greater than in the other tests.

27. The results show that it is cheaper to rebond with clay

after the sand has been used several times, than to rebond to a constant green compression strength. Just how long one can use a sand before rebonding depends upon the size of the casting and whether or not the sand would drop out of the molds upon working

TABLE 4
RESULTS OF DRY COMPRESSION TESTS

	Type of Molding Sand					
	Albany	Mulberry Grove	Bentonite	Constant-Strength Bentonite	Ohio	Constant-Strength Ohio
	Compression Strength in lb. per sq. in.					
Mold Test Method						
Original value.	30.0	52.5	93.0	93.0	71.0	71.0
Value after						
1st heat.	33.5	54.0	93.0	71.0	64.0	62.0
2nd heat.	13.0	65.0	93.0	93.0	69.0	62.5
3rd heat.	20.0	69.0	82.5	93.0	39.0	57.5
4th heat.	19.5	50.0	67.5	76.0	29.0	36.0
5th heat.	15.0	37.0	47.5	64.0	25.0	28.0
6th heat.	11.0	50.0	59.5	93.0	26.0	30.0
7th heat.	6.0	31.0	34.0	88.0	23.0	20.0
8th heat.	5.0	20.5	48.0	66.0	18.0	26.0
9th heat.	4.4	19.0	23.0	90.0	18.0	10.0
10th heat.	4.2	30.0	20.0	42.0	17.0	17.0
Oven Test Method						
Original value.	30.0	52.5	93.0	93.0	71.0	71.0
Value after						
800 deg. F.	23.0	44.0	64.5	81.0	47.0	58.0
1000 deg. F.	13.0	10.0	61.0	77.0	20.5	35.0
1200 deg. F.	8.4	5.5	27.5	60.0	10.0	14.0
1400 deg. F.	7.0	3.3	6.2	54.0	6.5	6.0
Hydration and Dehydration Method						
Original value.	30.0	52.5	93.0	93.0	71.0	71.0
Value after						
800 deg. F.	20.0	80.0	93.0	93.0	67.0	75.0
1000 deg. F.	6.6	10.0	80.0	82.0	22.0	37.0
1200 deg. F.	6.5	7.5	7.5	75.0	13.0	10.0
1400 deg. F.	6.0	5.0	4.0	75.0	5.0	7.0

it. No trouble of this nature was encountered during this investigation. This was due to the shape of the casting and the manner in which the molds were made. In actual practice, one would have to determine the limits of safe molding.

28. It is of interest to note the behavior of the normal bentonite sand in the dehydration test (Table 6). After tempering

TABLE 5
RESULTS OF CLAY AND FINENESS TESTS

	Original	After Mold Tests	After Oven Tests	After Hydration and Dehydration
Albany Sand				
On mesh No. 40.....	0.0	4.8	4.6	4.0
70.....	5.8	9.6	5.6	6.0
100.....	19.4	21.2	18.6	19.4
140.....	17.4	16.6	16.4	16.8
200.....	19.0	18.6	18.6	18.6
270.....	9.4	14.4	18.7	17.6
Clay.....	16.0	17.4	8.2	8.4
Total.....	98.0	99.4	100.1	99.8
Fineness No.....	146.0	130.0	143.0	144.0
Distribution No.....	136.0	143.0	148.0	147.0
Bentonite Sand				
On mesh No. 40.....	0.0	0.4	0.4	0.4
70.....	32.6	32.8	23.6	27.4
100.....	43.4	42.0	42.4	42.0
140.....	12.2	12.7	13.8	14.0
200.....	4.4	1.4	2.4	2.4
270.....	0.8	1.4	2.4	2.4
Clay.....	2.0	2.8	2.8	2.5
Total.....	4.6	3.5	4.0	3.6
Fineness No.....	100.0	99.8	99.2	99.3
Distribution No.....	72.5	75.0	83.0	76.0
	98.0	104.0	127.0	118.0
Constant-Strength Bentonite Sand				
On mesh No. 40.....		0.6	0.2	0.2
70.....		31.0	24.6	27.2
100.....		41.8	42.4	42.0
140.....		11.8	13.8	13.0
200.....		4.4	6.6	5.2
270.....		1.2	1.4	1.2
Clay.....		1.2	1.2	1.0
Total.....		8.8	9.2	8.8
Fineness No.....		99.4	102.0	98.8
Distribution No.....		71.0	77.0	74.0
		98.0	107.0	107.0
Mulberry Grove Sand				
Original	1.4	2.8	30.0	26.5
After Hydration and Dehydration	27.0	30.0	20.8	20.0
After Oven Tests	8.4	10.4	7.0	7.5
After Hydration and Dehydration	5.4	6.6	3.2	6.0
After Oven Tests	2.4	3.2	1.8	2.4
After Hydration and Dehydration	0.0	10.0	11.8	12.0
After Oven Tests	28.4	16.2	23.0	24.0
After Hydration and Dehydration	99.4	99.8	100.3	99.8
After Oven Tests	100.0	93.0	109.0	109.0
After Hydration and Dehydration	77.0	116.0	138.0	137.0
Ohio Clay Sand				
Original	0.0	1.0	28.8	26.6
After Hydration and Dehydration	28.2	38.4	39.0	39.2
After Oven Tests	11.4	12.2	7.0	12.2
After Hydration and Dehydration	4.4	1.4	1.4	1.4
After Oven Tests	1.6	2.6	3.1	2.0
After Hydration and Dehydration	13.2	8.6	11.5	11.8
After Oven Tests	99.4	99.5	99.6	98.8
After Hydration and Dehydration	74.4	77.0	83.0	76.0
After Oven Tests	114.0	111.0	127.0	110.0
Constant-Strength Ohio Sand				
Original		0.8	0.2	0.2
After Hydration and Dehydration		27.2	24.2	23.2
After Oven Tests		37.2	34.2	33.2
After Hydration and Dehydration		11.6	14.0	13.0
After Oven Tests		5.2	6.6	6.6
After Hydration and Dehydration		1.8	2.4	1.8
After Oven Tests		12.2	11.6	10.4
After Hydration and Dehydration		100.4	101.4	98.0
After Oven Tests		133.0	126.0	118.0

TABLE 6.
SAND LOSSES AND CLAY ADDITIONS

	Type of Molding Sand				Constant- Strength Ohio
	Albany	Mulberry Grove	Bentonite	Constant- Strength Bentonite	Ohio
Mold Test Method					
Original weight, grams.....	6000	6000	6000	6000 + 225 clay	6000 + 202 clay
Weight after 10th heat, grams.....	5445	5320	5470	6225	6202
Total weight lost, grams.....	555	680	130	5079	5415
Percentage lost.....	9.25	11.33	8.8	84.8	90.25
Weight of clay added, grams, after 1st heat.....	None	None	None	18.3	7.9
2nd heat.....	None	None	None	45	None
3rd heat.....	None	None	None	10	None
4th heat.....	None	None	None	None	42
5th heat.....	None	None	None	None	None
6th heat.....	None	None	None	20	None
7th heat.....	None	None	None	50	None
8th heat.....	None	None	None	10	None
9th heat.....	None	None	None	30	None
10th heat.....	None	None	None	30	None
Total weight of clay added, grams.....	None	None	120	10	50
Percentage of clay added.....	None	None	2.17	225	60
	None	None		4.4	202
					3.7

Table 6 (Continued)

Oven Test Method						
Original weight, grams.....	2500	2500	2520	2520	2520	2530
Weight after heating to 800 deg. F., grams.....	2455	2465	2465	2513	2507	2497
Weight after heating to 1000 deg. F., grams.....	2455	2443	2443	2498	2460	2503
Weight after heating to 1200 deg. F., grams.....	2443	2443	2453	2488	2378 + 30	2485
Weight after heating to 1400 deg. F., grams.....	2433	2425	2470	2470	2342 + 35 grms clay	2470
Total weight lost, grams.....	67	75	50	50	143	60
Percentage loss.....	2.68	3.00	1.90	1.90	5.6	2.35
Weight of clay added, grams.....	None	None	110	110	95	None
Hydration and Dehydration Method						
Original weight, grams.....	2500	2500	2520	2520	2520	2530
Weight after heating to 225 deg. F. for 4 hours, grams.....	2484	2491	2532	2532	2534	2523
Weight after heating to 800 deg. F. for 1 hour, grams.....	2445	2463	2528	2528	2529	2511
Weight after heating to 225 deg. F. for 4 hours, grams.....	2446	2475	2531	2531	2530	2517
Weight after heating to 800 deg. F. for 1 hour, grams.....	2436	2483	2532	2532	2530	2517
Weight after heating to 225 deg. F. for 4 hours, grams.....	2436	2483	2532	2532	2530	2517
Weight after heating to 1200 deg. F. for 1 hour, grams.....	2409	2410	2532	2532	2527	2516
Weight after heating to 225 deg. F. for 4 hours, grams.....	2397	2410	2525	2525	2515 + 40 grms clay	2510
Weight after heating to 1400 deg. F. for 1 hour, grams.....	2384	2406	2510	2510	2557	2505
(Sand was allowed to cool between heatings)					2540 + 30 grms clay	2485
Total weight lost, grams.....	116	94	10	10	22	38
Percentage loss.....	4.64	3.7	0.4	0.4	0.87	1.1
Weight of clay added to restore to original green compression strength, grams.....	None	None	100	100	70	None
						45
						1.5
						None

this sand to 5 per cent moisture, it was dried in the electric oven at 225° F. for 4 hours. The sand was then removed, allowed to cool to room temperature, and weighed. An increase of 12 gms. in weight was noted. When the sand was reheated to 225° F. for 4 hours, cooled and weighed again, and was then heated to 800° F. for one hour, cooled, and weighed, the sample still weighed 8 grams more than it did originally. All weights obtained were greater than the original ones until after the 1400° F. heat when a loss of 10 grams occurred. From Table 6 it may be observed that the weight of the sand increased from 2520 gms. to 2532 gms. after hydration and dehydration at 225° F. for 4 hours. The sand contained 120 gms. of clay and approximately 1 per cent water; this would account for the 12 gms. increase in weight. This weight was retained until after the sample had been heated to 1200° F. when dehydration took place.

MINERALOGY AND CHEMISTRY OF BONDING SUBSTANCES IN MOLDING SANDS

Testing Bonding Substances

29. As many of the results obtained could not be explained satisfactorily on the basis of the physical tests, the investigation was extended to include a study of the mineralogy of the bonding substances. The bonding substances of all sands used in the investigation were examined under the petrographic microscope to determine the mineralogical makeup and the size of the particles. The minerals were determined on the basis of their petrographic characteristics.³ An additional determination was made after the hydration and dehydration tests, and the petrographic data was obtained on the bonding substances to determine the change in the constituent minerals of the bond during the tests.

30. A difficulty encountered in the study of the natural molding sands was due to the presence of limonite ($2\text{Fe}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$) effectually obscuring the remaining minerals in the bond. Where limonite is present in abundance, it adheres to the surface of the particles, making impossible the identification of the mineral content with the petrographic microscope. Chemical analysis showed that the Albany molding sand contained 3.75 per cent Fe_2O_3 and 10.85 per cent Al_2O_3 , and the Mulberry Grove sand 2.78 per cent Fe_2O_3 and 8.85 per cent Al_2O_3 .

³ Petrographical determinations were performed by R. L. Grim.

Results of Petrographical Determinations.

31. The bonding substance used in the synthetic bentonite sands was composed of the clay mineral montmorillonite ($\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{XH}_2\text{O}$) which occurred in flake-shaped particles generally less than one micron (0.001 mm.) diameter. The clay was entirely crystalline. There were traces of other minerals, but the major constituent appeared to be montmorillonite.

32. Petrographic analysis of the bonding substances in the samples of bentonitic synthetic sands after the hydration and dehydration tests showed it to be still composed of montmorillonite in particles averaging one micron in diameter. It appeared to be unaltered, and had not yet lost its mineral identity.

33. The bonding substance used in the synthetic Ohio clay sands was composed chiefly of the clay mineral kaolinite ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$). This mineral occurred in flake-shaped crystals of all sizes up to 0.02 mm. in diameter, or 20 times larger in diameter than the crystals of the bentonite clay. Many of the crystals were near the maximum size and were book-like in form, due to the perfect cleavage of the crystals parallel to their bases. There were traces of other minerals, but the major constituent appeared to be kaolinite.

34. After hydration and dehydration tests, examination under the microscope showed that the Ohio clay was composed of a mixture of kaolinite in particles as large as 5 microns in diameter, and apparently of amorphous material. Kaolinite at 845° F. loses its crystal form, and above 1652° F. changes into mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) and a form of quartz (SiO_2). The material between the temperatures of 845 and 1652° F. is the transition state, which authorities do not agree upon. It must also be remembered that the original size of the kaolinite particles was 20 microns, or 0.02 mm.; a reduction in particle size of about 4 times is therefore shown.

35. The presence of limonite ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$) in the natural molding sand effectively masked the other constituents, so that the changes taking place in hydration and dehydration could not be determined precisely. Further research is necessary to accomplish the identification of the minerals in the bonding substance and to determine changes upon working.

Physical Properties of Minerals.

36. An inherent property of montmorillonite, the major con-

stituent of the bentonite clay, seems to be its high absorptive ability. According to Hoffmann, Endell and Wilm,⁴ "montmorillonite absorbs water in a reversible manner up to 1022° F. At 1472° F. montmorillonite lattice grouping is still intact, but breaks down at 1832° F. It seems that this breakdown of lattice grouping is preceded at about 1112° F. by the formation of an anhydromontmorillonite and the material is unable to swell any more." R. E. Grim⁵ shows that montmorillonite has lost most of its water of hydration between 932 and 1112° F. The exact mineralogical changes on heating montmorillonite to a high temperature have not been determined. However, it probably would change over to mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) and a form of quartz (SiO_2).

37. According to Schachtschabel,⁶ kaolinite absorbs water in a reversible manner up to a temperature of 806° F. However, the reabsorption of water is very slow. It takes over 110 hours at a temperature of 212° F. for kaolinite to reabsorb 4.3 per cent water after it has been heated to 806° F. Ross and Kerr⁷ show that kaolinite loses most of its water of hydration between 734 and 979° F.

36. After being heated to 842° F., kaolinite is altered mineralogically, and hydration is very slow, as already stated. At high temperatures (1652° F.) kaolinite eventually changes over to the mineral mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) and a high temperature form of quartz (SiO_2). There seems to be some question as to the exact condition of this material after being heated to temperatures between 842 and 1652° F. It appears to be non-crystalline Al_2O_3 and SiO_2 ; whether combined or uncombined is not agreed upon. It should be remembered that these temperatures are equilibrium temperatures, and in practice a considerable lag would no doubt exist as equilibrium is reached slowly.

39. The behavior of both montmorillonite and kaolinite when heated to high temperatures has been given some attention because it seems likely that, when using a molding sand containing kaolinite clay, the clay mineral would gradually break down into these two minerals, which would exist in small particles, possessing none of the properties of clay, but would remain in the molding sand and increase the quantity of silt. Thus, silt may be produced in a molding sand from the bonding substance as well as from the breaking down of silica sand particles.

⁴ ZEITSCHRIFT F. KRISTALLOGRAPHIE, vol. 86, pp. 340-348, 1933.

⁵ ECONOMIC GEOLOGY, vol. xxviii, No. 4, June 1933.

⁶ CHEMIE D. ERDE, vol. 4, pp. 295-419, 1930.

⁷ U. S. GEOLOGICAL SURVEY, Professional Paper 165, pp. 166-168, 1930.

40. According to Posnjak and Merwin,⁸ mineral limonite ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$), identified in the Albany and Mulberry Grove sands, loses its water of hydration at 356°F . Before this temperature is reached, limonite can be rehydrated with ease. After being heated to 356°F ., it ordinarily cannot be rehydrated to its original form.

Chemical Properties of Bonding Substances.

41. The base exchange⁹ capacities, or the ability of the clay minerals to hold either basic or acid ions on the surface of the materials, were determined, and the replaceable bases present were investigated in an attempt to interpret some of the results of the work.

42. The bentonite clay had a base-exchange capacity of 82 milli-equivalents per 100 grams of clay. This was saturated mainly with sodium ions, with smaller amounts of calcium and magnesium ions. The Ohio clay had a base-exchange capacity of 36 milli-equivalents per 100 grams of clay and was mainly a calcium and hydrogen clay. The Mulberry Grove sand had a base-exchange capacity of 7.7 milli-equivalents per 100 grams of sand and was mainly an acid clay, while the Albany sand had a base-exchange capacity of 2.9 milli-equivalents per 100 grams of sand, and was also mainly an acid clay.

43. The base-exchange capacities were obtained by leaching the materials with neutral ammonium acetate and washing out the excess of ammonium acetate with absolute methyl alcohol. The ammonia absorbed by the material in a replaceable form was determined by distillation into a standard acid solution after adding calcium carbonate, sodium sulphate, and water. The excess of acid was then titrated with a standard sodium hydroxide solution, and the exchange capacity calculated in terms of milli-equivalents per 100 grams of substance.

44. The base-exchange capacities of the bentonite clay and Ohio clay were determined on the whole clay substance, and the base-exchange capacities for the bentonite and Ohio clay sands were calculated. This was done by multiplying the base-exchange capacity of each clay by the percentage of each clay added to the silica sand. Thus, the percentage of bonding substance in the bentonite sand was 4.6. Therefore, $0.046 \times 82 = 3.77$ milli-equivalents per 100 grams for the bentonite sand, and 0.132×36

⁸ AMERICAN JOURNAL OF SCIENCE, vol. 97, pp. 311-348, 1919.

⁹ Base Exchange Determinations made by R. H. Bray.

= 4.75 milli-equivalents per 100 grams for the Ohio clay sand. It was not necessary to do this for the two natural sands because the clay substances were in the sands when received. The replaceable bases were determined by the usual semi-quantitative methods used in soil chemistry.

DISCUSSION OF RESULTS OF INVESTIGATION

Correlation of Physical and Chemical Properties of Minerals with Results of Investigation

45. An analysis of the results of the investigation indicates a direct relation between the physical and the chemical properties of the bonding substances. A comparison of the montmorillonite¹⁰ and kaolinite¹¹ sands on the basis of the green compression strength, shows that the bentonite (*i. e.* montmorillonite) molding sand had the longest life, or greatest durability of any sand investigated, when the percentage of bonding substances is taken into consideration. The strength decreased in accordance with the hydration curve for the principal constituent; namely, montmorillonite. This is shown by the oven test and hydration test results given in Table 2 and Fig. 2.

46. The green strength of this sand did not decrease until after the 1000° F. heat. At 1000° F., the green strengths of the bentonite sand were approximately equal to the original strengths. This agrees very closely with the hydration curve for the mineral montmorillonite. According to the authorities quoted, montmorillonite loses most of its water of hydration at 1022° F., and this loss is accompanied by the loss of its ability to rehydrate. This inability to rehydrate is also indicated by the test data which show a reduction in the green strengths of the bentonite sand.

47. *Particle Size.*—The petrographic results show that the size of the montmorillonite particles in the bentonite sand was 1 micron and less. This is, no doubt, responsible for the high green bond strength, and for the fact that the presence of only 4.6 per cent of the bentonite clay was sufficient to produce a green bond strength of 4 lb. per sq. in. at 5 per cent moisture content. The amount of Ohio clay necessary to produce the same strength was 13.2 per cent, or almost three times as great, and the average size of the particles in the Ohio clay mineral was approximately 20 microns (0.02 mm.). Therefore, a greater amount of the material

¹⁰ ZEITSCHRIFT F. KRISTALLOGRAPHIE, vol. 86, pp. 340-348, 1933.

¹¹ U. S. GEOLOGICAL SURVEY, Professional Paper 165, pp. 166-168, 1930.

(considering size alone) should be needed to produce a given green bond, green tension, and green shear strength.

48. *Kaolinite Properties*—This larger size of the particles of the kaolinite also accounts for the increase in green compression strength, of the sands when used. This results from a decrease in the size and an increase in the number of the kaolinite particles on being heated in the mold test, oven test, and hydration and dehydration test, thus causing an increase in the number of surfaces to which the tempering water could adhere, and the green strength of this sand increased in all cases even though heated to 1400° F.

49. According to authorities, kaolinite loses its ability to rehydrate at 842° F. This temperature is lower than that required for montmorillonite, and therefore sands containing the kaolinite mineral should lose their strength sooner than those containing montmorillonite. However, the Ohio clay sand increased in green strength until heated to 1200° F., but generally the final green strength was as great as the original green strength.

50. *Natural Sands*—As the petrographic examination of the two natural sands showed only the positive presence of the mineral limonite and doubtful indications of the identity of the major mineral constituent in the sands, further investigation must be undertaken before any reasons can be advanced for the particular behavior of these sands as related to the physical properties of the bonding substance.

51. *Synthetic Sands*—The green permeabilities of the two synthetic sands increased in all three methods. In the mold test, even though the sands were being dehydrated, some of the clay was removed by adhering to the surface of the castings. In the other tests, dehydration of minerals beyond the rehydration point accounts for most of the loss in bonding substances as shown in the clay and fineness tests, and also for the increase in green permeability, because the sands lost their water of hydration, and, therefore, increased in permeability.

52. For example, montmorillonite ($\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot x\text{H}_2\text{O}$) contains approximately 20 per cent water. From the results of the clay and fineness test (Table 5) it can be seen that the original bentonite sand contained 4.6 per cent clay. If it can be assumed that at 1400° F. the mineral was thoroughly dehydrated, and that after tempering this mineral is not capable of rehydration, then 4.6 per cent, which is the percentage of mineral contained in the

molding clay sand, and of which 20 per cent was water, multiplied by the fraction of water lost on dehydration, should equal the amount of water lost in the sand. Thus $4.6 \times 0.20 = 0.92$ per cent; 4.6 per cent $- 0.92$ per cent $= 3.68$ per cent. According to the results of the clay and fineness test of the bentonite sand after the dehydration test, it was found to contain 3.6 per cent bonding substance which is approximately equal to the computed value.

53. Likewise, the loss in bonding substance for the Ohio, Albany and Mulberry Grove sands can be estimated. (Kaolinite ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) contains approximately 13.9 per cent of water. The Ohio clay is a kaolinite, and the original Ohio sand contained 13.2 per cent clay. Therefore, $13.2 \times 0.139 = 1.83$ per cent, the loss from dehydration; $13.2 - 1.83 = 11.37$, which is the percentage of dehydrated kaolinite left in the Ohio sand. After the dehydration test there was found 11.8 per cent and after the oven test 11.5 per cent, close approximations to the computed value.

54. After the molding test, the percentage of bonding substance left was only 8.8. However, in this test, some of the bonding substance adhered to the surface of the castings, and, therefore, a greater loss in bonding substance would result. For the two natural sands, this calculation cannot be made, as the identification of the principal mineral constituents is doubtful. Probably future research can determine this.

55. The dry compression strength of the two synthetic sands were dependent to some extent on the mineral composing the bonding substances and its physical characteristics. The original size of the mineral also appeared to influence the dry strength of the sands. The original dry compression strength of the bentonite sand was 93 lb. per sq. in., while the dry strength of Ohio clay sand was lower. The dry strength of the two synthetic sands decreased for all three test methods. This was due to the mineral constituents being gradually dehydrated above the temperatures at which rehydration takes place.

56. The green strengths of the sand were influenced by the ability to withstand heat and by the size of the clay particles. The results of the tests of the constant-strength sands show that, although it was possible to maintain the green compression strength by additions of clay, the dry strength decreased. This again indicates that the green strength of molding sand depends upon the size of the particles in the bonding material, together with its bond-producing capacities because as the bond was dehydrated, it also

was becoming smaller in crystalline size. The dry strength of a molding sand, in contradistinction to this, is dependent upon the physical or chemical properties of the bonding material or upon a combination of both physical and chemical properties. This is apparently substantiated when the base-exchange capacities of the sands investigated are considered.

57. *Base-Exchange Capacities*—An analysis of the results indicates a direct relation between the amount of material, or materials, which possess base-exchange properties, and the dry strength values of the sands. Table 7 shows the calculations which were made substantiating this. If it is assumed that the material in all the sands which contributes principally to the dry strength value is identical with, or similar to, the mineral montmorillonite appearing in the bentonite clay used in the present study, some interesting relationships appear.

58. As montmorillonite is a mineral having a high base-exchange capacity, and as it appeared to be a very pure material, it was arbitrarily given the base value of 100. The base-exchange capacity of 82 milli-equivalents per 100 grams was used as the basis for the calculation in Table 7.

59. The ratio of the dry compression strength to the base-exchange capacity of the four sands used is constant, as would be the case if the base-exchange capacities were a direct measure of the dry compression strengths. If, therefore, the original assumption is correct, another factor, or factors, must be influencing the results obtained. This factor appears to be the amount of the bonding substance not possessing base exchange properties. Since it has been assumed that a mineral, or minerals, equivalent to the bentonite used is responsible for the exchange properties, the bentonite equivalent can be calculated as

$$\frac{\text{base-exchange capacity of the sand}}{\text{base-exchange capacity of bentonite}} \times 100$$

60. If this is subtracted from the bonding substance value (bonding substance—bentonite equivalent), the amount of inert fine material in a mineral is obtained (col. 5, Table 7). This fine material, which possesses no base-exchange properties, although it has formerly been measured as part of the bonding material, contributes nothing to the dry initial strength values of the sand, and actually represses the effect of the bentonite equivalent, which can be considered as a measure of the true bonding substance for the dry strength values as far as practical use is concerned.

TABLE 7
BASE-EXCHANGE CAPACITIES OF MOLDING SANDS

Type of Molding Sand	Percentage of Bonding Substance	Base-Exchange Capacity Milliequivalents per 100 grams	Actual Determined Dry Compression Strength lb. per sq. in.	Bentonite Equivalent*	Non-bentonite Fine Material per cent†	Calculated Dry Compression Strength if 100 per cent Pure lb. per sq. in.‡	Difference Between Calculated and Determined Dry Compression Strengths lb. per sq. in.§	Depressing Effect of Non-bentonite Equivalent for each per cent lb. per sq. in.¶	Calculated Initial Dry Compression Strengths of Sands lb. per sq. in.**
Mulberry Grove.....	28.5	7.7	52	9.4	19.1	192	140	7.3	62
Albany.....	4.0	2.0	32	3.5	18.5	122	42	6.5	28
Normal Bentonite.....	4.6	3.77	93	4.6	0.0	93	0	0	93
Normal Ohio Clay.....	13.2	4.75	71	5.8	7.4	119	48	6.5 Av. 6.8	69

*Bentonite equivalent = $\frac{\text{base-exchange capacity}}{82} \times 100$.

†Percentage of bonding substance = bentonite equivalent ÷ non-bentonite fine material.

‡Base-exchange capacity $\times 24.6$ = calculated dry compression strength in lb. per sq. in., if 100 per cent pure.

§Calculated initial dry compression strength - actual determined dry compression strength.

¶Depressing effect of non-bentonite equivalent per each per cent = $\frac{\text{difference between calculated and determined dry compression strengths}}{\text{non-bentonite fine material}}$

**Calculated initial dry compression strength of sand, in lb. per sq. in. = Calculated dry compression strength of sand, if 100 per cent pure - (percentage of non-bentonite fine material \times depressing effect of non-bentonite equivalent for each per cent).

61. If it is assumed that bentonite is the ideal bonding substance, it can be calculated that, for each milli-equivalent of base-exchange capacity added as bentonite, an increase of $\frac{93}{3.77} = 24.6$ lb. per sq. in. dry compression strength is represented.

62. Based on this assumption, it appears that the dry compression strength value of each milli-equivalent per 100 grams of bentonite equivalent is approximately 25 lb. per sq. in., while the depressing effect of the non-bentonite equivalent is approximately 6.8 lb. per sq. in. for each per cent present, as indicated in Table 7.

63. While the number of cases investigated is too small to reach a definite conclusion as to the practical use of these values, a possibility for further research is suggested and it is indicated that, in the future, the values for bonding material and base-exchange capacity can be used to estimate the initial dry strength values of a molding sand. As an example of this method the following is given: A sand had a base-exchange capacity of 4.75 milli-equivalents per 100 grams, and the amount of bonding material in the sand was 13.2 per cent.

Calculations:

$$\frac{4.75}{82} \times 100 = 5.8 \text{ "bentonite equivalent."}$$

$$13.2 - 5.8 = 7.4 \text{ "Non-bentonite equivalent."}$$

$$4.75 \times 25 = 118.7 \text{ lb. per sq. in. dry compression strength, if 100 per cent pure.}$$

$$7.4 \times 6.8 = 49.3 \text{ lb. per sq. in. depression in strength due to non-bentonite.}$$

$$118.7 - 49.3 = 69.4 \text{ lb. per sq. in. initial dry compression strength the molding sand should have.}$$

These values were taken from the Ohio clay sand, and the result of the calculation compares favorably with the experimental value of 71.0 lb. per sq. in. original dry compression strength as shown in Table 3, column 5, Ohio sand.

64. It should be noted that the relationship found between the base-exchange capacities and the dry strengths of the four materials used are purely assumed, and need not be entirely a result of the special chemical property of base-exchanges. The fineness and nature of the clay possession this property must also be considered. The size distribution within the material smaller than 1 micron in size is probably one of the important factors controlling the properties of the molding sands. The relationship suggests, however, that base-exchange capacity, size distribution, and mineral nature should form the basis for future studies.

SUMMARY OF RESULTS

65. The following is a summary of results obtained in this investigation:

(1) Graphical correlation of the results of the methods investigated shows that the two natural and the bentonite molding sands gradually decreased in both green and dry strengths, and that both the green and the dry permeability increased during the tests. The green strength of the synthetic Ohio clay sand first increased and then decreased, and there was a gradual decrease in all dry strengths while the green strengths increased. The green and the dry permeability of this sand showed a gradual increase with all three methods. The loss in green and dry strengths of the two natural and the normal bentonite sands was due either to the bonding material adhering to the surface of the castings or to the dehydration of the principal mineral constituent in the molding sand. The increase in green strength of the normal synthetic Ohio clay sand was due primarily to the breaking down of larger sized clay particles into smaller ones, thus increasing the green strengths. The decrease in dry strength of this sand indicates that dry strengths of a molding sand are independent of size of particles and depend upon the dehydration resistance of the major mineral constituent; while the initial dry strength can be measured by the base-exchange capacity of the bonding substance. The behavior of the two natural and "bentonite constant sands" seems to substantiate this theory.

(2) The results of the clay and fineness tests showed that the grain fineness of the sands was reduced and the grains were distributed differently after each of the three methods of testing for durability. This is shown by an increase in the numerical values of the fineness and distribution numbers of the sands. The loss in bonding material of the normal synthetic sands, as represented by the clay test, shows that in the hydration and dehydration test this loss is approximately equal to the water of hydration contained in the bonding material. In the mold test, some of the bonding material adhered to the castings, thus making it impossible to calculate the bond lost.

(3) Correlation of the results of the clay and fineness tests of the sands with the green strengths, dry strengths and

permeability tests, shows that all of the sands could be rebounded with clay and put to further use for molding purposes. This was proved by the results of the tests on the two synthetic constant-strength molding sands. In actual practice, when facings of graphite are used, a reduction in permeability would result.

(4) The results indicate that if the base-exchange capacity of a molding sand is known, the original dry compression strength can be calculated by means of the following formulae:

$$\frac{\text{Base-exchange capacity of sand}}{\text{Base-exchange capacity of bentonite}} \times 100 = \text{bentonite equivalent.}$$

Amount of bonding substance—bentonite equivalent = amount of inert finer mineral, or non-bentonite equivalent.

Base exchange capacity of sand x dry compression strength of each milli-equivalent of bentonite = lb. per sq. in. dry compression strength if 100 per cent pure.

Non-bentonite equivalent x depressing effect of non-bentonite equivalent = lb. per sq. in. depression in strength.

Dry compression strength if 100 per cent pure — lb. per sq. in. depression in strength = initial dry compression strength the molding sand should have.

CONCLUSIONS

66. As a result of this investigation, the following general conclusions may be drawn with respect to the objects of the investigation as outlined in the introduction:

(1) It is not possible to accurately predict the life of a molding sand by any of the three methods.

(2) It is more economical for foundrymen to add clay or bonding substance to molding sands after using the sand for a number of heats, than to try to hold the strength constant by frequent additions of bonding substance, as was done with the two constant-strength sands used in this investigation. Results also show that the amount of bond necessary to bring a given quantity of molding sand back to its original green compression strength depends entirely on the kind and nature of the bonding material used.

67. Additional conclusions to be drawn from the investigation are:

(3) The durability of a molding sand depends upon the physical and chemical properties of the mineral, or minerals, found in the bonding substance. The green strengths seem to depend upon the physical properties of the mineral, or minerals, and on the size of particles, and can be measured by the base-exchange capacities. The original dry strengths of a molding sand apparently are independent of the size of particles and the physical properties, and are dependent upon the presence of the mineral or minerals carrying base-exchange capacity, and the amount of non-bentonite fine material present in the bonding substance.

(4) More samples of bonding substance should be investigated so as to determine whether the results obtained in this investigation are applicable to a greater variety of molding sands. The fineness and nature of the clay possessing the property of producing green and dry strengths in molding sands should be considered in future research. The size distribution within the material smaller than 1 micron in size also cannot be overlooked as an important factor in controlling the properties of molding sands. Future investigation should also be conducted on the natural molding sands with the object of devising a suitable method of separating and identifying the mineral or minerals present, so that the life or durability of natural molding sands can be determined.

ACKNOWLEDGMENT.

68. The results presented in this paper were obtained in connection with an investigation conducted by the Engineering Experiment Station of the University of Illinois in cooperation with the American Foundrymen's Association. The work at the experiment station was conducted under the supervision of M. L. Enger, Dean of the College of Engineering and Director of the Experiment Station and O. A. Leutweiler, Professor of Mechanical Engineering Design and Head of the Department of Mechanical Engineering.

DISCUSSION

Presiding: R. F. HARRINGTON, metallurgist, Hunt-Spiller Manufacturing Co., Boston, Mass.

MEMBER: We know there are different grades of bentonite, that is,

different locations where it is mined. I would like to ask the speaker if he knows where the bentonite that they have tried comes from.

MR. SCHUBERT: We, for our own personal benefit, left that up to the Committee on Durability. This clay was picked by that committee. As I understand, it so happened that they gave us the purest one they could get. I believe Mr. Dietert had the choice of this clay, and I have forgotten, Mr. Dietert, just exactly where you got it.

H. W. DIETERT¹: It was shipped from Wyoming.

MEMBER: That answers my question.

N. J. DUNBECK²: In the paper the statement is made that bentonite bonded sands have the highest durability when the amount used is taken into consideration. I think that statement is probably true literally. I wonder, however, if the qualifying phrase would be given sufficient attention and whether the actual results here will be studied closely enough to give the practical importance of the statement. We know that in a foundry we must add a certain, definite amount of bentonite to give us the required strength, or must add a certain definite amount of clay bond to give us whatever strength is required. I believe we are concerned mostly with the question—What is the durability of these materials in the quantities in which we actually use them?

We have the results in this paper. The required amount of each material was used to give the desired strength. We find that in the series of tests where the material was run ten heats with no additions of bonding material, that the bentonite clay had lost 75 per cent of its strength, while the fire clay bond had lost only 47 per cent. At the end of the ten heats, the fire clay still had double the strength of the bentonite. I point this out only because this general statement that appears in the paper that bentonite bonded sands have the highest durability when the amount used is taken into consideration may be misleading. We might follow that statement with a further statement that under actual operating conditions, as shown in these tests, the fire clay bond does have much higher durability.

MR. SCHUBERT: Of course, in making a series of tests like this, especially at a university, we try to conduct them as impartially as possible. All that was meant by that statement was that, considering the amounts of bonding materials in those two sands, that it seemed that bentonite had the greater durability or life. It is true that the actual figures show a greater loss in the bentonite in bonding strength than the Ohio clay. Perhaps another way of looking at it would be this—if we had put the same percentage of clay in the two samples and saw what happened, then maybe we would have had a different story. However, we had so many variables and so many different tests going on at the time, that we did not see how it would be possible to do that. It would just prolong the investigation. I am willing to concede that a qualifying statement should be made to the effect that the actual figures show that Ohio clay lost less bond strength than the bentonite as the clays were tested in the investigation.

¹ President, Harry W. Dietert Co., Detroit, Mich.

² Eastern Clay Products, Inc., Eifort, O.

E. H. KING^a: Mr. Schubert, I would like to bring up the point that you are comparing the working strength of the clays against the renewal strength of the molding sand. By that statement, I mean that it does not seem to be fair to compare the shipped strengths of a naturally bonded molding sand with the strengths of a silica sand and bond mixture, as the naturally bonded sand purposely has an excess of bond whereas the latter mixture is usually prepared with only enough bond to provide proper working properties.

The work you have done is exceedingly valuable, but I am afraid that a foundryman reading this paper in a casual manner, might receive the wrong impression as to the final conclusions to be drawn. In other words, you started with two natural sands, one from New York and one from Illinois. Apparently at the beginning of the research you discarded the two natural sands but continued with the clay and bentonite. Since you did not carry the experiments further along to state definitely the amount of new natural sand additions necessary to maintain "working strengths," I feel that this part of the paper should be deleted and the entire paper devoted to the facts concerning the two materials actually under test.

I also notice that you chose two molding sands, two clays, and then in addition to the two clays you chose to separate constant strength bentonite and constant strength clay. Why did you not follow that procedure regarding the natural molding sands insofar as strengths and permeabilities, and so on, are concerned?

MR. SCHUBERT: Because one would have to use 100 per cent natural sand to get back the original strength. That was tested and that was found to be true. In other words, if one takes a natural sand and casts in it once or twice it is going to lose green strength and dry strength. To bring the strength of sand back to its original green strength, whatever that may be, one would have to use 100 per cent of the sand. Therefore, one would be using 100 per cent new sand all the time. But with the synthetic clay, one can add only the clay bond material to the base, whatever that may be, and that will bring the green compression strength back. Does that answer the question?

MR. KING: You were comparing the "working strengths" of the clays against the "renewal strength" of the molding sand such as you would in the foundry?

MR. SCHUBERT: Yes. Those classified as natural sands were shipped in just as they came out of the deposits.

MR. KING: It is then entirely impossible to correlate those figures of the natural sands with molding clay.

MR. SCHUBERT: No, I would not say it is impossible at all, so far as natural sands are compared with molding clay. I did not mean by my statement that it is impossible to add natural molding sand to a natural sand heap and still make castings. What I did mean was that it would be impossible to get the original strength back.

^a Hougland & Hardy, Inc., Evansville, Ind.

Report* of Steel Division Committee on Foundry Sand Research

To the Steel Division:

During the past two years it has been the function of your committee on Steel Sands and Refractories to act as a liason committee between the Foundry Sand Research Committee and the Steel Division; particularly to present to the joint group the problems of specific interest and application to the Steel Division; to make available to the Steel Division the results of the work and the progress of the joint research group; to receive and act on specific or general problems of the Steel Division; and to undertake such research and development as may be of a strictly steel foundry nature and lying distinctly outside of the normal function of the joint committee.

During the past year very definite progress has been made by this committee; its value having been particularly enhanced by a change of personnel, the following now being members of this committee in addition to your chairman:

H. W. DIETERT, Harry W. Dietert Co., Detroit, Mich.

W. FINSTER, Reading Steel Casting Co., Reading, Pa.

D. L. PARKER, General Electric Co., Lynn, Mass.

H. D. PHILLIPS, Dodge Steel Co., Philadelphia, Pa., and

D. C. ZUEGE, Sivyer Steel Casting Co., Milwaukee, Wis.

Aims of the Committee

In recent years the Steel Division, as a group, has made remarkable progress in advancing its metallurgic knowledge, but it has been felt that similar strides have not been made in the field of steel sand behavior knowledge to keep pace with increased metallurgic development. By its work and through publication of its progress and recommendations, it is the aim of this committee to bring to the steel foundrymen a realization of the importance and value of proper knowledge of sand properties and behavior. It is hoped that this committee can be instrumental in increasing the scope and technique of sand testing and bring to the steel foundry-

* Presented before Steel Division Session, 41st Annual Convention, Milwaukee, Wis., May 6, 1937.

men the knowledge, the equipment, and procedure necessary for the optimum development of this phase of steel foundry science.

Report of Current Year's Activities

While a full report of the activities of the Foundry Sand Research Committee appears elsewhere in the Proceedings of this convention, some of its work of particular value to the Steel Division can profitably be reviewed here.

During the current year, the Foundry Sand Research Committee has undertaken a complete revision of its pamphlet "Testing and Grading of Foundry Sands". In the new edition which will shortly be published a number of tests such as dry compression and shear, have been made standard, the procedures for sampling of sand have been more definitely outlined, the tolerances permissible on specimens for testing have been made closer to improve accuracy, and standardized tests on synthetic sands and bonds have been included. A hardened permeability tube has been substituted for its greater accuracy and permanency. The Foundry Sand Research Committee has also undertaken, during the past year, the writing of a pamphlet, defining and describing a very wide range of properties of sands dealing with each property in individual pamphlets. This pamphlet will be an adjunct to the pamphlet on "Testing and Grading of Foundry Sands" and should prove extremely valuable.

Dry Compression. Perhaps due to the fine work of Briggs and Gezelius on free contraction of steel, the importance of the contraction and expansion of sands has become of great interest, particularly to the steel foundrymen. Short of actually studying the behavior of sands at elevated temperatures, there is no test available to the foundryman that comes so near to predicting the behavior of his sand in the mold than the test for dry compression and the various factors which affect this property. The green compression test of a molding sand measures strictly its value in ramming up and stripping of patterns in the mold; but while it is true that to some extent the dry strength is related to the green strength of the sand and is more or less proportional to it, dry strength is much more nearly an accurate measurement of the mold behavior in the presence of molten metal, than is green strength. The dry compression strength is perhaps the most sensitive test available to the foundrymen in predicting probable mold behavior. For this reason your committee was instrumental in having adopted as

standard the dry compression strength test and aided in development of an accessory to the Dietert type CP machine which made it possible to measure the dry strengths up to a limit of 350 lbs. per sq. in. This accessory equipment has, however, not proved altogether satisfactory for the steel foundrymen; first, because a good many steel sands have dry strengths in excess of 350 lbs. and, second, because this lever crushing mechanism functions partly in shear, especially on specimens slightly below the 2 in. standard size, giving somewhat erroneous results. It was, therefore, the recommendation of your committee to the joint group that a separate hydraulically operated unit, operating with two indicating stop dials with separate valves, be designed to make dry compression tests. One dial to be graduated from zero to 150 lb. per sq. in., and the second dial from zero to 1000 lb. per sq. in.

Since dry compression properties are governed not alone by the quantity of clay or bentonite present in the sand, but also by the amount of cereal in the sand, and its rate of break down and ultimate strength are conditioned by the relative quantities of cereal and clay or bentonite, this committee is undertaking a refinement specifically applicable to steel sands of the tentatively adopted standard procedure developed by the chairman of this committee some years ago for the qualitative differential determination of organic and clay binders in used foundry sands. The tentative procedure is being distributed to the various members of the committee, who will each apply in their own laboratories and report their results and possible recommendations for change in this procedure. The committee wishes to stress to the technical foundrymen the extreme importance of so testing his sands; particularly in those foundries where some proportion of used sand is present in either heap or facing, as accurate control of these two bonding media, whose high temperature behavior is totally different, must lead to lower losses due to contraction, strains, and fissures in castings.

High Temperature Effects. Perhaps the most important work of this committee has been in originating and carrying on a series of tests on the behavior of sands at elevated temperatures. This program has been recently altered to confine the work of this committee entirely to steel sands.

In view of the fact that comparatively little knowledge is available on this subject, the committee felt that a basic program to develop equipment and technique of testing, and to furnish fundamental basic information on behavior of mold materials should con-

stitute the scope of the initial program, rather than tests on surface effect and finish. This portion of the work, it is hoped, will follow on the basic program below outlined.

The program adopted consists of testing a number of typical steel sands bonded initially with silica jell to determine the difference in behavior due to structural differences of the sands and then successively bonded with cereal, clay and bentonite in simple combinations. In addition, an average type silica sand is being mixed with bentonite and cereal, and fire clay and cereal to make typical steel foundry mixes for testing and to these standardized mixes is added one core mix consisting of silica sand, silica flour and linseed oil.

The types of sand tested include a rounded grain sand of average fineness, a sharply angular sand, and a sub-angular sand of similar grain size, and a fine silica sand of sub-angular structure, together with a natural bonded steel molding sand.

These sands are being tested for their physical properties and then subjected to tests at 2900° F. for their contraction and expansion behavior their compression strength characteristics at intervals of 100° F. up to the maximum temperature on both heating and cooling, and also are being tested for their behavior under sudden thermal shocks at 2900° F.

On the typical foundry mixes above listed, it is planned to re-bond these sands to their original strength after heating to determine the effect of sand re-use.

Photomicrographs of the bond and grain structure, both before and after heating, are included in this series of tests which should throw light on the structural changes occurring due to thermal conditions. It should be emphasized that these tests represent simple thermal behavior uncomplicated by the chemical effects of metal, metallic oxides and silicates which are normally present under mold conditions.

Sieve Tests. This committee has discussed and is making a series of tests with intermediate sieves especially adapted to steel foundry requirements between the 30 and 40, 50 and 70, and 70 and 100 mesh screens. It is hoped shortly to have a definite recommendation for adoption. It has long been a demonstrated fact that in average steel foundry sands having practically identical standard screen analysis, there is a radical difference in permeability and in general sand behavior which is attributed to the distribution of the grain sizes intermediate between the screens

now standard. The additions of the screens above listed, it is hoped, will furnish data making the selection of sands more specific.

Future Program

During the coming year, the committee contemplates making a study of the pamphlet of the Foundry Sand Research Committee, if necessary adding additional chapters of special interest to the steel foundry division. It expects to give some consideration to the study of surface thermal effects and finish in relation to high temperature behavior of sands, but this will only be attempted after a large portion of the tests, above outlined, are completed.

The committee has given considerable thought to the matter of clay testing, and particular reference to clay as a bonding material, and recommendation has been made to the Foundry Sand Research Committee that an additional study be given to this procedure, tending to make it more accurate. This has been referred to the proper sub-committee for action; this committee cooperating with the sand research group.

Refractories

While so far this phase of the work, allotted to this committee, has seen very little in the way of concrete results, it is planned in the coming year to define and inaugurate a program of study of refractory material, particularly to the plastic type. To this end, tests are being conducted on the analysis of clay materials, determining in these tests the relationship between the plastic and clay substance content. A procedure is being studied for testing slaking rate, optimum moisture content, drying, and dehydration shrinkages, with a view to correlating these various factors with the proper application of refractory materials.

Respectfully submitted,

R. E. APTEKAR, *Chairman Steel Division
Committee on Foundry Sands and
Steel Division Representative on Com-
mittee on Foundry Sand Research.*

Report of Committee on Radiography

Report of Steel Division Session of the 41st Annual Convention, Milwaukee, Wis., May 4, 1937.

Presiding: Major R. A. Bull.

CHAIRMAN BULL: The first item on the program for this session, is the report of the Steel Division Committee on Radiography and Steel Castings which is to be presented by Mr. C. W. Briggs, the chairman of the committee. Mr. Briggs.

MR. BRIGGS¹: *Members of the Steel Division and Guests:* Our plan in presenting the committee report is to have various individuals of the committee at this time present discussions on different phases of this work.

The committee was organized with the expressed purpose of preparing and presenting some information on radiography for the Steel Division and to give foundrymen a general idea of the possibilities of radiography, what is known on the subject, where they could find it, and to give them the opportunity to project a certain amount of discussion on the general subject.

One of the plans of the Committee was to point out to the Steel Division members where they could obtain literature on the subject, that is, for both x-ray and gamma ray radiography. The Committee also planned that if the American Society for Testing Materials had a symposium on radiography during the year at which material was to be presented, that it would not be necessary to duplicate that material for this Society. The American Society for Testing Materials did prepare a symposium last June in which the whole subject was very well taken up. It has now been printed and is called "Symposium on Radiography and X-Ray Diffraction". This is one of the 1936 Volumes of the American Society for Testing Materials. We would suggest that anyone who is vitally interested, or who has even the slightest interest in the subject, obtain one of these books and go over certain papers in it rather carefully. These papers and a general summary of what they contain, are as follows:

"The Principles of the Radiographic Process" by John T. Norton. Dr. Norton outlines in detail the method and the technique of x-ray radiography. He takes up the relations that exist between the various factors entering into the production of a successful radiograph and discusses photographic film or paper, intensifying screens and other technical features, such as the x-ray source and the knowledge that the operator must have with the method. That is, he tells in detail how one should go about it to obtain a good x-ray radiograph. The technique is very important, especially if one wishes to obtain a representative radiograph. Almost anyone can prepare a radiograph with nothing on it, but that does not necessarily mean that the casting is free from defects. An excellent radiograph consists of good employed technique. This is rather

¹ Physical Metallurgist, U. S. Naval Research Laboratory, "Bellevue," Anacostia Station, D. C.

a matter of study and experience, and a lot can be learned from this paper.

Following that paper, there was a paper by Ernschaw Cook, entitled, "Foundry Application of Radiography." This is indeed a very interesting paper and we thought that it would be wise to include that material on this program so as to give the foundryman an idea of what can be done in the way of x-ray work in the foundry when the x-ray is used as a tool to help him produce good castings. Mr. Hewitt, who is a member of our committee, promised to prepare this material for us as quite a bit of the work had been done by the American Manganese Steel Co. Mr. Hewitt, unfortunately, was unable to be here, but Mr. Christie of that organization is here and will review this material for him.

The next subject that was taken up in the symposium was radiography in the welding shop. Castings are often radiographed after they have been welded to inspect the soundness of the weld. This is a good resumé of what can be expected of radiography when dealing with defects due to welding. The subject should be very interesting reading to everyone.

The next subject in the symposium prepared by Mr. Mochel deals with gamma ray radiography. Mr. Mochel gives the technique of gamma ray radiography in a very complete manner. Along with the paper is included a section on procedure and technique which has been prepared by the Naval Research Laboratory, pioneers in this line of work. Practically everyone who is using gamma ray radiography is using the technique as established by the Naval Research Laboratory. Mr. Mochel discusses gamma ray radiography and its adaptability to the steel casting industry. He also points out how it differs from x-ray radiography and explains how its individual characteristics can be put to good advantage. The two methods, it should be understood, are not competitors of each other—they more or less supplement each other.

Outside of this symposium, there have been other papers published during the year on the subject of radiography, but none of them is as complete as those in the symposium. This, therefore, takes up the entire subject with regard to what has happened during the past year.

We now pass on to the second portion of the report, namely the inspection of x-ray and gamma ray radiographs and their interpretation. I am going to ask Mr. Ash, who is a member of the committee, to discuss this section.

E. J. ASH²: In the radiographs which are to follow, examples of steel castings will be exhibited showing defects attributed to slag, sand, gas holes (due either to wet sand or improperly deoxidized metal), hot tears and also shrinkage of the type due to solidification.

The interpretation of defects shown in a radiograph becomes less uncertain with experience. In many cases, the defects appearing on a radiograph are removed from a casting, thus giving the radiographer an excellent opportunity to study the actual nature of the defect. It is this type of experience that soon enables correct interpretation and identification of defects revealed.

² Assist. Professor, Dept. of Metal Processing, University of Michigan, Ann Arbor, Mich.

When radiographic inspection was first introduced as an inspection tool by the U. S. Navy in one of its Navy Yards, certain steel castings from the U.S.S. Maryland were sent in for inspection. These castings had been subjected to repeated impact in gun fire over a period of years but had not failed in service. The radiographic inspection revealed a number of hot tears in these castings. These tears, however, were not located in the most highly stressed regions of the casting. The unfitness for service of a casting showing internal defects is not an easy matter to determine. There are no fixed standards with which to judge, and owing to the multiplicity of factors involved, it is often very difficult to arrive at a decision.

It may be well to point out that one of the benefits to be derived from radiographic examination is the thorough inspection of pilot castings. This method alone has been of great value to a number of foundries, and the hearty cooperation of the radiographer and the foundry has resulted in eliminating many of the unseen weaknesses that are prone to appear in cast metals. Radiographic examination has opened a new channel for the steel castings manufacturer to produce a higher quality product at little extra cost.

NOTE: Mr. Ash showed several slides of radiographed castings and had on display castings from which these were made.

MR. BRIGGS: We will now proceed with the third section of the report. It was suggested that the committee review the subject of radiography from the standpoint of costs of equipment in order that the foundryman may have a general idea of the outlay. In that manner we have asked Mr. Gezelius to present a short discussion on costs. Mr. Gezelius.

R. A. GEZELIUS¹: X-ray equipment for radiographic inspection in the steel foundry can be divided into two main classes; equipment suitable for radiographing thicknesses of steel less than $2\frac{1}{2}$ to 3 inches and equipment suitable for radiographing thicknesses greater than 3 inches. These classes can be sub-divided into stationary and portable equipment and also by the manner of construction, that is, open type construction which depends upon the surrounding air for insulating purposes and the closed, or oil immersed type. Practically all portable equipment is of the oil immersed type as these units can be made more compact because of the greater insulation offered by the oil. Another advantage of oil immersion is that the unit can then be weather-proofed and used out-of-doors even in rain. It is dangerous to use equipment of the open-type out-of-doors except when conditions are ideal.

The prices of x-ray equipment vary considerably with the size and type of construction used in the unit. 200 KV units, suitable for radiographing up to $2\frac{1}{2}$ to 3 inches of steel vary in price from \$3,000 to \$9,500, depending upon whether or not the unit is to be stationary or portable and of the open or oil immersed type of construction.

¹ Division of Physical Metallurgy, U. S. Naval Research Laboratory, Anacostia, D. C.

The larger units, 300 to 400 KV, suitable for thicknesses of $4\frac{1}{2}$ to 5 inches, vary in price from \$8,000 to \$14,000. The lower prices being for stationary and, usually open-type construction.

A portable, oil immersed, unit suitable for radiographing up to $3\frac{1}{2}$ to 4 inches of steel, can be obtained for approximately \$11,000.

The initial cost in gamma ray radiography depends entirely upon the amount of radium required. The amount of radium needed will depend upon the average wall thickness to be examined and the speed with which the examination must be carried on. The smallest amount that would ordinarily be practicable is about 100 milligrams. An average size source is about 200 milligrams and except for very thick sections, there should be no need for capsules larger than 300 milligrams. The approximate price at the present time is \$30.00 per milligram.

Radium is also available for rental in amounts of 100, 200, 400 and 500 milligrams. The rental price is \$10 per 100 milligrams for a twenty-four hour period of use.

The prices quoted above do not include such accessories as developing tanks, film drying racks, developing hangers, dark-room illuminators, intensifying screens, etc. The total cost of these accessories, necessary for both x-ray and gamma-ray radiography, will vary from \$150 to \$250, depending upon the number and type of each item obtained.

The other necessary expenses will include dark room facilities, a lead lined room or portable lead shields if x-rays are used, and if gamma rays are used, a lead lined container for the radium.

CHAIRMAN BULL: Mr. Gezelius, It would be interesting to those here if you will summarize the expense of the equipment, including an x-ray room, and equipment that might be required for examining sections not exceeding 4 inches in thickness, having a possible maximum length of 15 feet.

MR. GEZELIUS: A portable x-ray machine that will penetrate $3\frac{1}{2}$ to 4 inches will cost approximately \$11,000. The accessories will run roughly \$100.00 to \$200.00. The cost of the dark room, of course, depends upon the price of labor and the materials construction. So \$12,000 should cover the cost for x-ray equipment.

With gamma rays, the cost depends entirely upon the size of the source desired. A 200 milligram capsule, which will handle practically all of the ordinary commercial work with reasonable exposure time, will cost about \$6,000. A lead lined container for the radium can be built for \$50.00. The other expenses would be the same as with x-rays, that is, \$200.00 for the accessories and the cost of the dark room.

MR. BRIGGS: In the fourth section of this report the Committee wanted to emphasize the fact that radiography is a tool that can be used in the production of steel castings. At the present date radiography is mostly used by the inspectors as a check-up on the finished product, but the Committee feels that the foundryman should use it to ascertain if his casting practice is producing the desired results. With this in view, the committee decided to present that portion of Mr. Cook's paper that

deals with the radiographing of pilot castings. Mr. Christie will present that material in slide form.

(The slides shown by L. D. Christie, American Manganese Steel Co., Chicago Heights, were the illustrations from paper entitled "Foundry Applications of Radiography" by E. Cook, which appears in The Symposium on Radiography and X-Ray Diffraction Methods," American Society for Testing Materials, Proceedings 1936, p. 25.)

MR. CHRISTIE: I do not believe you can make any diagnosis without showed in which the castings had grooves machined to varying depths, and where you had a deviation of about $2\frac{1}{2}$ per cent in depth, do you not believe they illustrate the necessity of carefully examining the surfaces of all castings without attempting to interpret the x-ray film without the examination of the casting?

CHAIRMAN BULL: Mr. Christie, relative to those slides which you having the film and casting together. Very often there is a little excess metal or something which will show up on the x-ray film, or a little gouging that will show up as thinner metal. You will find it is right on the surface and not the fault of the casting at all.

MR. BRIGGS: One of the most important subjects before our Committee is the problem of radiographic inspection. We have discussed it in detail, but as yet we have nothing tangible to offer. We, however, would like to call to the attention of Steel Division members the section presented by Dr. Lester, in the A.S.T.M. volume on radiography, which deals with radiography inspection. The subject is too long to be presented here even in summary form, but I would certainly advise all who are interested in the subject of inspection, to read it.

During the last year, the steel casting industry has had thrust upon it one or two specifications on radiography. Some of the foundrymen here have operated under radiographic clauses, others have definite ideas concerning such specifications. It is along this line the Committee would like to have some general discussion on what you think about radiographic inspection. To start this discussion, Mr. Wilson, a member of our Committee, is going to present a few remarks.

L. C. WILSON*: Our experience with x-ray, as far as specifications go, is quite limited. We have had some slight experience with it. Personally, my feeling is that there are a great many pitfalls when radiography or x-ray is applied to the acceptance or rejection of castings in the foundry. We do believe, although we are not practicing radiography for our own information at the present time, that there is a great deal to be learned by the foundryman in producing better castings. But in the state of the art of the interpretation of films we feel that there is a particular danger when it is to be used in the rejection or an acceptance specification of a casting with a defect.

In some of the specifications there have been intimations that the defects must be classified. At the A.S.T.M. symposium last year there

* Reading Steel Casting Co., Division, American Chain and Cable Co., Reading, Pennsylvania.

were shown films illustrating the acceptable and unacceptable in weldings. And if this is applied to castings without any reference to the function that the casting is going to perform or that takes into account the stressed portions of the casting, I think we are going to find that the foundry is going to bear quite a burden of rejection where the casting may be perfectly good for the service for which it was intended. I believe we will have to study specifications as they come out and express our opinions. Our opinions, of course, must be based upon factual evidence and a great many times there are castings which possibly can be cut up and the defects found fully as well as by x-ray. But, I do believe that this trend is something that the foundry industry must give particular consideration to or we are going to find specifications wished on us that will be pretty difficult to meet and furnish castings that are acceptable to our customers.

CHAIRMAN BULL: Mr. Willson has touched upon an extremely important phase of this subject of radiography. There are several men here who have been prominent in helping the development of steel casting specifications and who have directed attention to some specifications that have called for radiographic examination. The time is opportune now for any of those gentlemen to speak their piece on this subject as it ought to be clarified to some extent.

E. W. CAMPION²: The Association certainly is again deeply indebted to Mr. Briggs and his committee members who have presented this program to us this afternoon for doing some further pioneering in a direction looking towards a better product in the steel castings industry. I think everyone who is interested in improving the quality of steel castings will recognize the fact that non-destructive testing is here. I think every progressive manufacturer will feel that he must inform himself about what are now, as it seems to me, the early stages of non-destructive testing, among them, of course, gamma ray and x-ray. There are few foundries, I know, that have the equipment for such testing. The equipment is expensive. It is, however, available. If we had the equipment, the first thing necessary for us to do, obviously would be to develop the technique to get good films. After we have obtained good films, the next step, of course, would be to find out what they mean.

All of you perhaps shared the feeling that I had when I looked at the films Mr. Christie has shown us, and that was that Mr. Christie may have one idea and you and I may have another of what the films show. Those differences, of course, may be reconciled in some way. In other words, immediately ahead of gamma ray or x-ray examinations is the establishment of criteria for arriving at correct conclusions. Because, when you see a radiographic film, there are three questions presented: Shall the casting be rejected? Shall it be repaired? Shall it be accepted? Well, if there are three or four of us looking at it at the same time, I suppose there will be three or four different answers until a correct basis is established for the passing of judgment.

As the matter stands at the present time, it appears to me the average

² President, The Bonney-Floyd Co., Columbus, Ohio.

foundryman who makes steel castings subject to radiographic examinations must be prepared to accept without any question someone else's judgment as to what the films mean and he must let this someone else give the answer to those three questions. Because as he stands, the ordinary foundryman at the present time cannot contribute very much specific experience about it. About the only thing he would do would be to put up as much resistance, if the answer was to reject the casting or repair it, as he possibly could and then finally cave in and bow to the inevitable.

A question that arises from a casual looking at these films is the matter of depth. Where is the defect? How far away from the surface is it? Does the defect occur in a part of the casting which will subsequently be removed by machining? If it does and the depth is not evident from the radiographic film, you may decide to throw away many, many good castings that would be otherwise acceptable. So we must find some way of deciding depth.

Another element required in the examination of radiographic films, would be the history of the casting. Much depends upon its circumstances of pouring and its analysis and a great many other factors which do not occur to me now but on which I am quite sure you have to have the same kind of information. I do not think any competent metallographist would attempt to make an interpretation of a photomicrograph unless he knew a lot about the history of the material. I am sure that some kind of history will be required in interpreting x-ray films. As I say, it seems to me this whole matter is in the early stages of its development, and I think we ought to encourage men like Mr. Briggs, Mr. Christie, and others who are interested in it, to carry the work on so we may have more specific information, in order that we may get faster towards the establishment of the most definite possible criteria for acceptance or rejection.

Another factor that occurs to me in this connection is the matter of cost. It may be that specifications requiring radiographic examination will unduly increase the cost to the purchaser, especially if such examination is required where there is not any particular necessity of applying it. Any one of you, even though you did have long experience with x-ray examination or gamma ray examination, would undoubtedly want to charge much more money for the production of a given casting subjected to that specification than you would if it were subjected to ordinary specification. So I feel purchasers of castings made subject to radiographic examination should give some consideration to the question of cost.

P. E. McKINNEY⁶: I can fully share Mr. Campion's views as to the value of this discussion to all of the steel foundries. When radiography was first discussed among foundrymen, everybody had more or less the viewpoint that this was just some other imposition of a tough specification that was going to make life more miserable. A careful review of the results of the questionnaire sent out by Dr. Lester containing his contribution to this last symposium will be very interesting and instructive.

There are other angles to radiography than that of an inspection tool. With proper development and proper interpretation and the proper use of

⁶ Metallurgical Engineer, Bethlehem Steel Co., Bethlehem, Pa.

the results, it is going to be a distinct help to steel foundrymen rather than another tough requirement that is imposed on them as rejection specifications.

There are several big commercial users of steel castings who are practicing for their own information radiography as a part of the inspection that very few steel foundrymen here know about. I have seen some such instances, and I have seen cases where castings, for very important applications, without the benefit of some internal diagnosis which can be made with radiography, would have been thrown out. I mean the designer would not have dared to take a chance on the possibility of severe internal conditions which he could not disclose without cutting the casting up when it was too late to do anything with that particular casting. I have seen several instances during the past year where the intelligent use of the results of radiographic examination has actually saved castings which were in a rejected status and which without radiography even the producer of the casting would not have had the nerve to ask them to use.

We could mention many instances, leading to the thought that perhaps the consideration of radiography by steel foundrymen may develop into quite an asset in helping us to instill in the users a greater confidence in steel castings. If we are going to take the viewpoint that I have seen certain people take, in connection with radiography, that it is a detective to help to throw out more castings and to catch the crooked steel foundryman at some new tricks, that is not going to develop radiography progressively along the lines we want. We have all seen cases where the radiographist has said anything but a clear film is unacceptable. We have seen other practice where the radiographist looks at the area, considers the purpose of the casting and the function of the particular location that he is examining and even though it does show some unsoundness, if the service in which the casting is to be used will not endanger it, he says, "We will let it go; it is perfectly satisfactory."

The most encouraging angle that I have seen in radiography has been several statements that have been made in discussing the results of radiographic examination with designers to the effect if radiography is continued, we will have to design for radiography. In other words, they have to do just what was advocated in the paper that was presented this morning on the design of steel castings. And the radiographist will become design conscious. He will find out there are certain inherent conditions for which design is responsible, and the uncovering of that by radiographic examination is going to rub it in a little.

Now I believe every steel foundryman should view radiography not only from the angle of inspection, but from the angle of how much it is going to help him in selling better ideas of symmetry in design to the designers and selling to the users who are quite suspicious at times of the general integrity of castings that we have a sound product and can prove it sound. It is along those angles that we are going to accomplish a great deal if steel foundrymen will look at radiography as a possible help as well as an imposition of an additional requirement.

CHAIRMAN BULL: Mr. Briggs, I suppose you subscribe to the comment made by Mr. Christie, following a comment I made, that it is

extremely advisable and the only safe course to make an interpretation by examining the film and the casting? If you have any contrary opinion, will you please express it.

MR. BRIGGS: I have no contrary opinion.

CHAIRMAN BULL: The reason I asked that question was because I think it bears directly on one objection that has been raised by a number of steel foundries regarding radiographic inspection. As we all know, the acceptability of many steel castings is determined by an inspector at the foundry. The great need for correct interpretation has been emphasized here today. In some cases I am quite sure the foundryman has been accused of obstructing scientific progress because he has been fearful that the interpretation either will be made by an inspector who cannot be expected to be thoroughly familiar with the casting art, or because the interpretation might be made several hundred miles away by a man who would have no opportunity to examine the casting and get the related information which is needed for correct interpretation.

I believe that explains to some extent some objections that have been raised by steel foundrymen to the acceptability of steel castings according to the examinations of films.

Simplified Cost System and Foundry Business Record for the Gray Iron Foundry Industry*

The general lack of any basic records in small foundries for the assembling of data essential to cost information has prompted building of the "Foundry Business Record," which is a combination bookkeeping and cost finding system and is in absolute accordance with the Uniform Cost and Estimating System.

It must be borne in mind that there is considerable over-emphasis on the amount of time and clerical help required to handle the additional work, and also the high cost of installation. With this in mind, the "Foundry Business Record," while being low in cost, contains all the required information and is so flexible that it may be expanded as a member of the Industry required additional knowledge of his business. The combining of cost and bookkeeping records greatly simplifies the entire operation, and the use of this method will permit bookkeepers to devote considerable time to handling of other details.

Forms 1 and 2 (pages 708 to 711) are special journal sheets, and while shown as two forms, when printed, one form will show on each side of a single sheet.

Form 3 (pages 712 and 713) A combination Payroll and Distribution sheet.

Form 4 (page 714) A Recapitulation of Cost Data from general ledger, assembled to give cost of melted metal and departmental overheads.

Form 5 (page 718) Cost Estimate Sheet or Card for use as detailed on pages 718 and 719.

Carefully Follow These Instructions

(1) All money transactions being handled through a Bank, columns are provided to record such transactions. Deposits are entered under "Debit" columns; customers "**credited**" for their payments under **Acts. Rec.** (Sales) by date as shown in its columns and **name** with explanation in their proper columns.

* This cost system is that of the GRAY IRON FOUNDERS' SOCIETY (copyright 1936) Cleveland, O. It was presented for discussion before the Cost Session of the Annual A.F.A. Convention, Milwaukee, Wis., May 7, 1937.

Checks drawn on Bank are entered in Credit Column and their numbers noted in the "Check No." columns, showing to whom drawn (under name) with **explanation**.

(2) Every entry of any kind should show **date** in proper column.

(3) In Accounts Receivable (Sales) columns are entered amount of each invoice covering shipment to customers under "debit." Under "credit" payments on account (re-paragraph 1) **or** for invoices **from** customer **or** for invoices **from** customer covering returns, etc. Total **weight** of shipment covered by each invoice entered in Column provided.

(4) In Accounts Payable (Purchases) columns are entered amounts of invoices covering supplies, expenses, etc. under "credit" after receipt of these items and under "debit" when these invoices are paid.

(5) Sundry Column is to be used for items not specifically covered otherwise, such as Capital Accounts, Special journal entries, charges which occur infrequently during the month, purchase of machinery, tools, equipment, etc.; Discounts (both allowed and taken); charges to sales occasioned by return of castings as referred to in paragraph (3) "Invoices from Customers." **ALL INDIVIDUAL ITEMS IN THIS COLUMN ARE POSTED DIRECT TO THEIR RESPECTIVE ACCOUNTS IN THE LEDGER AS DETERMINED FROM THE EXPLANATION COLUMN.**

(6) Distribution of the important items of operation is carried out in Form 2 and care should be taken to enter these charges correctly under the various headings. Under Pig Iron and Scrap, the invoices covering these respective materials are entered together with freight and delivery charges.

(7) Under Expense, are entered those invoices, etc., covering charges of expense, materials, supplies, etc. which can be properly charged to the various departments as shown by one of the following methods of distribution:—Actual or Estimated Departmental consumption; Departmental Payroll; Departmental Floor Space or Departmental Equipment Value.

(8) Care should be taken to make proper Classification of labor charges when made on Form 3, Payroll Distribution Sheet,—at the time the regular payroll is made up when drawing check or checks,—should be distributed under their respective Classification of Form 2 of "Foundry Business Record." Daily time or job tickets or cards simplify the collection of this information and should be used where and when possible to do so.

(9) The total "debits" of Forms 1 and 2 as they face each other in the binder should exactly balance the "credits" of the same forms. The totals of the columns are carried forward to their respective columns on the next sheets ahead before starting new entries.

(10) At the end of the month the totals of all columns except "Sundry" which items are posted directly as covered in paragraph (5) are posted to their respective accounts in the Ledger. NOTE: After posting Debit and Credit totals of Accounts Receivable to the Ledger, credit Sales Account in Ledger in the same amount of Debit Total Accounts Receivable as it represents total sales for the period.

(11) The various forms enumerated have been worked out in such a manner as to represent one month's review of the majority of transactions of foundry activity. It will be noted from a comparison of these Forms that all transactions may be followed through the entire detail.

Form No. 4—Recapitulation

(12) On Form No. 4 "Recapitulation" the information is transferred from the respective Ledger Accounts into the proper columns which you will note have been numbered and an explanation shown directly under each number.

(13) The method of arriving at the cost per pound of metal will be identical, whether computed on a monthly basis or an annual basis.

(14) The example shown on Form 4 at the top is arrived at from a Cupola Charging report such as is now used by many foundries. As this method of reporting daily Cupola Charges has been widely distributed, we do not include a form for this particular practice.

(15) Another method is available for use in this connection, but is not at all recommended except for foundries whose production is very, very small. This method consists of taking a complete physical inventory of the materials used in charging the Cupola at the start of a period, adding all purchases during the intervening period, and subtracting the inventory at the end of the period; this sum is then divided by the total number of pounds of good castings produced between the two inventory periods, the result being the cost of the metal used. As above stated, this method is satisfactory for a small foundry where no serious problem is encountered in securing a physical inventory,

FORM 1

BANK

GENERAL

Debit	Credit	CHECK No.	DATE	NAME	EXPLANATION
			Feb.		
	10.00	63	1	B. Smith	Pd. by ck—Tool Repairs
125.00				King Machine Co.	On a/c
			2	J. Cohen	Inv. 2/1-Scrap
			4	Adams Co.	Shipment
				Dale & Brown	Shipment
600.00				Force Machine Co.	Shipment & Ck. on a/c
				City Hardware Co.	Inv. 2/2-Fork & Shovel
				Ohio Sand Co.	Inv. 2/2
200.00			6	A. B. Jones Co.	Shipment & Check rec'd.
				Dale & Brown	Shipment
500.00				Force Machine Co.	Check on a/c
	495.00	64		J. Cohen	Ck. Inv. 2/1-1% Disc.
			8	Force Machine Co.	Shipment
				Dale & Brown	Shipment
			11	State Oil Co.	Inv. 2/9
				City Hardware Co.	Inv. 2/9-Nails, Wire, Etc.
				King Machine Co.	Shipment
				Force Machine Co.	" & Inv. 2/6 & Return
			14	Pitt Iron Co.	Inv. 2/10
	1501.00	65		Payroll	To Date
			16	Adams Co.	Shipment
475.20				Dale & Brown	" & a/c less 1% Disc.
600.00			19	A. B. Jones Co.	Shipment
				Black & Co.	Shipment
			23	Beehive Coke Co.	Inv. 2/20
				City Power Co.	Inv. 2/20
				Lake Sand Co.	Inv. 2/18
				Foundry Supply Co.	Inv. 2/22-Chaps. Core Oil
			26	King Machine Co.	Shipment
				Adams Co.	" & Ck.-1% Disc.
653.40				Force Machine Co.	" & Ck. rec'd.
			28	Dale & Brown	Shipment
				Black & Co.	Shipment
	1539.00	66		Payroll	To Date
3653.60	3545.00				TOTALS

FORM 1—LEFT SECTION OF PAGE OF GENERAL ACCOUNTS

ACCOUNTS		ACCOUNTS RECEIVABLE		SUNDY		ACCOUNTS PAYABLE	
Weight	SALES		ACCOUNTS		PURCHASES		
	Debit	Credit	Debit	Credit	Debit	Credit	
							1
							2
		125.00					3
						500.00	4
7000	420.00						5
5500	330.00						6
9000	450.00	600.00					7
						25.00	8
						140.00	9
4500	292.50	200.00					10
2500	150.00						11
		500.00					12
				5.00	500.00		13
5000	250.00						14
4000	240.00						15
						60.00	16
						80.00	17
5000	325.00						18
11000	550.00	60.00	60.00				19
						868.00	20
							21
4000	240.00						22
6000	360.00	480.00	4.80				23
2000	130.00	600.00					24
10000	630.00						25
						120.00	26
						150.00	27
						60.00	28
						80.00	29
2000	130.00						30
6000	360.00	660.00	6.60				31
7000	350.00	500.00					32
4500	270.00						33
5000	315.00						34
							35
100000	*5792.50	3725.00	71.40	5.00	500.00	2083.00	36
	(*Cr. Sales)						

FORM 1—RIGHT SECTION OF PAGE OF GENERAL ACCOUNTS

DISTRIBUTION

CUPOLA				MOLDING DEPT.			
METAL		MELTING DEPT.		DIRECT	INDIRECT	EXPENSE &	DIRECT
Pig Iron	Scrap	Labor	Exp & Sup	Labor	Labor	Supplies	Labor
10		12	13	21	22	23	31
1							
2			10.00				
3							
4	500.00						
5							
6							
7							
8			5.00			10.00	
9						140.00	
10							
11							
12							
13							
14							
15							
16							
17						10.00	
18							
19							
20	868.00						
21		52.00		580.00	322.00		130.00
22							
23							
24							
25							
26			120.00				
27			22.50			37.50	
28							
29						30.00	
30							
31							
32							
33							
34							
35		58.00		620.00	278.00		120.00
36	868.00	500.00	110.00	157.50	1200.00	600.00	227.50
							250.00

FORM 3

PAYROLL FEB. 28th, 1936

DISTRIBUTION

LABOR ACCOUNTS												
Name	Clock No.	Hrs.	D.W. Rate	Earnings	Cupola Labor 12	Mold Direct Labor 21	Mold Indirect Labor 22	Core Direct Labor 31	Core Indirect Labor 32	Clean & Ship. 42	Variable Labor 102	Non-Variable Labor 112
J. Bate	101	50	.60	30.00	30.00							
S. Cuto	102	40	.70	28.00	28.00							
S. Pearl	202	80	PW	64.00		64.00						
A. Brown	203	80	.75	60.00		60.00						
S. Cast	204	80	PW	60.00		60.00						
J. Kulek	205	80	PW	64.00		64.00						
E. Smith	206	80	PW	64.00		64.00						
W. Block	207	80	.60	48.00		48.00						
S. Jones	210	80	PW	48.00		48.00						
K. Zabo	211	80	PW	48.00		48.00						
P. White	214	80	PW	60.00		60.00						
J. Green	215	80	.80	64.00		64.00						
B. Redd	217	50	PW	40.00		40.00						
S. Pack	252	80	PW	40.00			40.00					
J. Roll	254	80	PW	40.00			40.00					
K. Tarr	256	80	PW	40.00			40.00					
D. King	257	80	.45	36.00			36.00					
R. Fry	258	80	.40	32.00			32.00					
C. Peters	259	80	PW	32.00			32.00					
J. Ray	260	80	PW	32.00			32.00					
M. Spiro	262	65	.40	26.00			26.00					
W. Gray	303	80	.45	36.00				36.00				
P. Ford	305	80	.40	32.00				32.00				
A. Link	306	80	.40	32.00				32.00				
R. Lang	308	40	.50	20.00				20.00				
J. Wise	351	50	.40	20.00					28.00			
M. Mach	352	50	.40	20.00					20.00			
A. Myer	402	80	.40	32.00						32.00		
B. Ott	405	70	PW	28.00						28.00		
L. Perry	407	70	PW	28.00						28.00		
K. King	408	80	PW	32.00						32.00		
O. Long	409	70	.40	28.00						28.00		
W. Laub	411	70	.40	28.00						28.00		
G. Rule	412	50	.50	25.00						25.00		
J. Tarr	413	60	.40	24.00						24.00		
J. Banks	415	50	.40	20.00						20.00		
J. Porter												
Foreman		70	1.00	70.00							70.00	
O. Haup	510	80	.65	52.00								52.00
J. Migan	511	80	.60	48.00								48.00
					1539.00	58.00	620.00	278.00	120.00	48.00	245.00	100.00

NOTE:—

- Account #12 Cupola Men and Chargers—Melting Dept. Labor.
 Account #21 Molding Dept. Direct Labor—Molders and Helpers.
 Account #22 Molding Dept. Indirect Labor—all other labor.
 Account #31 Core Dept. Direct Labor—Core Makers.
 Account #32 Core Dept. Indirect Labor—all other labor.
 Account #42 Cleaning and Shipping Labor.
 Account 102 Variable (Overhead) Labor—Foreman each Dept.
 Account 112 Non-Variable (Overhead Labor—General foreman and general labor.

FORM 3—AN EXAMPLE OF COMBINATION PAYROLL AND DISTRIBUTION SHEET

FORM 3

PAYROLL FEB. 14th, 1936

DISTRIBUTION

Name	Clock No.	Hrs.	D.W. Rate	Earnings	LABOR ACCOUNTS								
					Capable Labor 13	Mold Direct Labor 21	Mold Indirect Labor 22	Core Direct Labor 31	Core Indirect Labor 32	Clean & Ship. 43	Variable Labor 102	Non-Variable 113	
J. Bates	101	40	.60	24.00	24.00								
S. Cuto	102	40	.70	28.00	28.00								
S. Pearl	202	80	PW	64.00		64.00							
A. Brown	203	80	.75	60.00		60.00							
S. Cast	204	80	PW	60.00		60.00							
J. Kulek	205	80	PW	64.00		64.00							
B. Smith	206	80	PW	64.00		64.00							
W. Block	207	80	.60	48.00		48.00							
S. Jones	210	80	PW	48.00		48.00							
K. Zabo	211	80	PW	48.00		48.00							
P. White	214	80	PW	60.00		64.00							
J. Green	215	80	.80	64.00		64.00							
S. Pack	252	80	PW	40.00			40.00						
J. Roll	254	80	PW	40.00			40.00						
K. Tarr	256	80	.50	40.00			40.00						
D. King	257	85	.40	34.00			34.00						
R. Fry	258	85	PW	34.00			34.00						
C. Peters	259	80	PW	32.00			32.00						
J. Ray	260	80	.40	32.00			32.00						
M. Spiro	262	65	.40	26.00			26.00						
L. Long	264	80	.55	44.00			44.00						
W. Gray	303	80	.45	36.00				36.00					
P. Ford	305	80	.40	32.00				32.00					
A. Link	306	80	.40	32.00				32.00					
R. Lang	308	40	PW	20.00				20.00					
A. Alt	310	20	PW	10.00				10.00					
J. Wise	351	70	.40	28.00					28.00				
W. Mach	352	60	.40	24.00					24.00				
A. Myer	402	80	.40	32.00						32.00			
B. Ott	405	70	.40	28.00						28.00			
L. Perry	407	70	.40	28.00						28.00			
K. Bing	408	80	.04	32.00						32.00			
O. Long	409	70	.40	28.00						28.00			
W. Laub	411	70	.40	28.00						28.00			
G. Rule	412	50	.50	25.00						25.00			
J. Tarr	413	10	.40	4.00						4.00			
J. Porter													
Foreman		60	1.00	60.00							60.00		
O. Haup	510	80	.65	52.00								52.00	
J. Migan	511	80	.60	48.00								48.00	
					1501.00	52.00	580.00	322.00	130.00	52.00	205.00	60.00	100.00

FORM 3—AN EXAMPLE OF COMBINATION PAYROLL AND DISTRIBUTION SHEET

FORM 4

RECAPITULATION

FORM 4

Castings on hand Feb. 28th
Shipments during February

21,652 Lbs.
96,075 "

117,727 "

21,864 "

Less Castings on hand Feb. 1st

(1) 95,863 "

Metal charged during month of February
(secured from cupola reports or inventories)

57,144 Lbs.	pig iron #1	@ 21.70 Gross Ton	.969	\$553.74
21,427 "	pig iron #2	@ 21.20 Gross Ton	.946	202.70
19,568 "	purchase scrap	@ 10.00 (2) Net, Ton		97.84
50,000 "	gates and sprues (remelt)	@ 10.00 (2) Net Ton		250.00
148,139 "	total melt			\$1104.28
Less 5,282 "	melting loss (see par. 15)			
142,857 "				
Less 47,143 "	remelt iron on hand end of period @ \$10.00 (2) Net Ton			235.71
(1) 95,714 "	good castings (64.7% yield)			\$ 868.57
		.9074c per Lb. \$18.15 Net Ton		

(1) The figure 95,863 Lbs., as shown by inventory and shipments, should equal 95,714 Lbs., but there is usually a slight variation due to errors in weighing.

(2) Current market price of scrap.

CALCULATION OF OVERHEAD

All charges shown are for the month of February. Account Nos. 110-111-112 are computed on an annual basis and then divided by 12 to give correct charge for one month.

ACCOUNT NO.	13	23	33	43	Totals
Based on use of all supplies, etc., purchased during month of Feb.	Cupola Expenses & Supplies	Molding Expenses & Supplies	Cure Room Expenses & Supplies	Cleaning & Shipping Exp. & Sup.	
Account #100—(power (a) light & heat included) See Journal Distribution	157.50	227.50	197.50	142.50	725.00
Account #110 (taxes (b) insurance & depreciation) 1/12 of annual	6.67	87.50	15.00	36.66	145.83
Account #111 Depreciation (c) on equipment—1/12 annual	25.00	50.00	12.50	37.50	125.00
#101—Workmen's Comp'n (d) #102—Var. Gen'l Labor #112—Administrative 1/12 annual	(4.1%) 34.17	(66.4%) 553.33	(12.9%) 107.50	(16.6%) 133.33	833.33
(e) Indirect Labor	110.00	600.00	100.00	450.00	1260.00
(f) Unproductive Expense Tot.	333.34	(i) 1513.33	(k) 432.50	(m) 804.99	3089.16
(g) Direct Labor		(j) 1200.00	(L) 250.00		1450.00
(h) Metal cost from top of page, .9074c Lb.	868.57				868.57
Totals	1201.91				5407.73

Cost of iron at the spout, 95,714 Lbs. of good castings
Per pound of good castings
Use

1201.91
1.255c
1.26c

but in the majority of plants, the cost of securing a physical inventory periodically far exceeds the cost of keeping an accurate cupola charging record. However, for accurate cost of melted metal, the use of both daily cupola reports and the inventory, as a check of each record, is recommended. In either practice account must be taken of the melting loss which can be determined by your own experience. This is the difference between the tonnage charged in and the total tonnage tapped out.

(16) We now come to the calculations of overhead. It will be noted that the first item (a) Account 100—Power, Light and Heat included—is taken direct from the attached Journal and distributed directly to each Department in the proportionate share of its use. (See Flow Chart, Page 717.)

(17) **Account No. 110**—Taxes, Insurance and Depreciation, Item (b), are annual charges; these charges should be divided by twelve (12) and shown in the General Ledger under the proper heading as a charge for each month of the year. The method of distribution used for this particular item is based on the percentage of floor space of each Department to the total floor space of the Plant.

(18) **Account No. 111**—Depreciation and Insurance on Equipment, Item (c). This item also should be set up in the General Ledger on a monthly basis. (See Flow Chart, Page 717.)

(19) **Account No. 101**—(Workmen's Compensation).

Account No. 102—(Variable General Labor) Item (d).

Account No. 112—(Administrative Expense).

are distributed on a payroll percentage basis. It will be noted that the percentages have been worked out, and are directly over the Departmental charges. (Check these percentages with your own payroll distribution.)

(20) **Indirect Labor** Item (e), is the total Departmental Indirect Labor as shown in the Journal.

(21) **Unproductive Expense** Item (f) is the total of all Monthly Expenses, Item 1 to 7 inclusive, which represents the burden of each department in the respective columns.

(22) **Melting Cost Per Pound.** By again referring to the cost of metal reported at the top of Form 4 you will note that the return for the month of February is 95,714 lbs. of good castings, the melting cost per pound is \$333.34 divided by 95,714 lbs., which gives a melting cost of .3482c per lb.

(23) Item (g) is the Direct Labor of each Department for

the month, and under this method is shown for molding and core room.

(24) Item (h) Metal Cost is taken directly from the Recapitulation at the top of Form 4, which shows 95,714 lbs. of good castings with a total metal cost of \$868.57, or a cost of .9074c per lb.

(25) By dividing the total of all Cleaning and Shipping Labor and Expense by the number of pounds of good castings produced, the answer is the average cost of cleaning and shipping per lb. Or, by dividing all Cleaning and Shipping Labor and Expense by the total Direct Molding Labor the answer is the per cent Cleaning and Shipping Cost.

(26) It must be borne in mind that these figures have been used only for the purpose of demonstration and will in no way affect any figures which you may secure from your own operation.

Explanation of Form 4

Molding overhead is arrived at by dividing molding unproductive expense by molding direct labor.

Molding Direct Labor	Molding Unproductive Expense
1200.00 Item (j)	1518.33 Item (i)
1200) 1518.33(126.52	or Molding burden 126.52%

Core overhead is arrived at by dividing core unproductive expense by core direct labor.

Core Direct Labor	Core Unproductive Expense
250.00 Item (l)	432.50 Item (k)
250) 432.50(173.00	or Core Burden 173%

Cleaning cost per pound of good castings .8410c or

Cleaning Cost	Molding Direct Labor
804.99 Item (m)	1200.00 Item (j)
1200) 804.99(67.0	or 67.0% of Molding Direct Labor

Explanation of Cost Estimate Sheet or Card (Page 718)

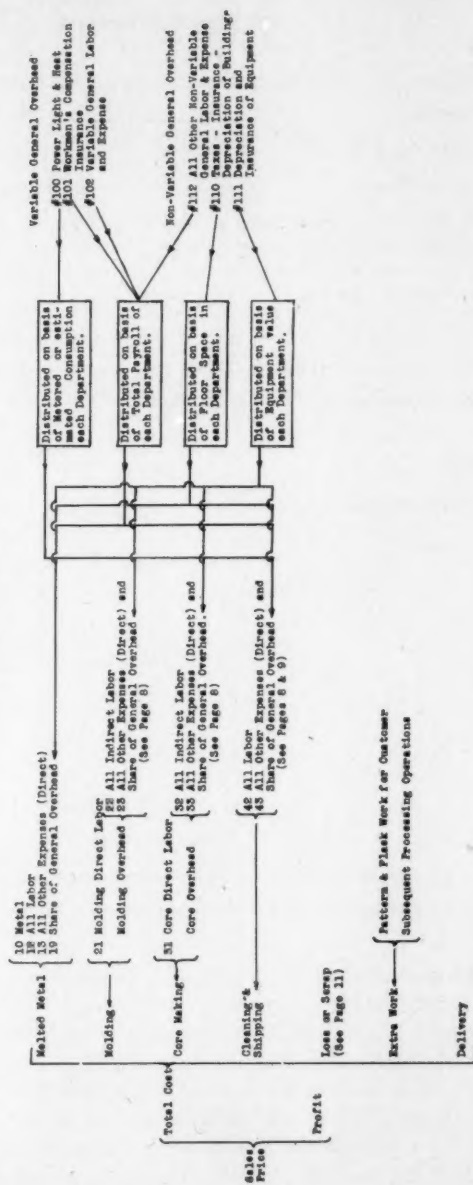
Line A, B, C and D should be filled in with information supplied by the customer on his request for quotation.

Line E can be easily filled in and the final result will show the total production per day.

Under Iron and Melt, your total weight per day, multiplied

FLOW SHEET

GRAY IRON FOUNDERS' SOCIETY, INC.

SIMPLIFIED COST & ESTIMATING PROCEDURE
FOR SMALL FOUNDRIES

Cost Estimate Sheet or Card

(A) Customer..... Pattern No.....
 (B) Description..... Date.....
 (C) Pattern Equip. Flask Quantity.....
 (D) Core Box Equip. No. Cores per casting.....
 (E) Wt. each Wt. per Mold Molds per day Wt. per day #

	Est.	Actual
Iron & Melt # @ equals		
Alloys # @ equals		
(1) Mold Price ¢ per Molds		
Molding Overhead %		
(2) Core price ¢ per Cores		
Core Overhead %		
Cleaning Expense # @ ¢ or % of direct molding cost		
Scrap		
Extras		
Total cost		
Profit %		
Freight		
Total Sales		
Selling price per pc. or lb.		

(1) For day work put molders and helpers total pay for day in estimated column.

(2) For day work put coremakers total pay on number of cores of one day's molding.

by the cost of Iron at the spout, will give you the total cost of iron for the day's production.

Under Alloy, use the weight and price of alloys necessary to make the particular casting.

Molding Cost is for a total day's production. As explained in footnote (1), if the molders are on a day work basis, the total day's pay should be entered in the estimate column.

Molding overhead: Use the proper per cent as worked out

on your recapitulation sheet and take this percentage of the molding price.

The same procedure is followed for core cost and core overhead. (See Footnote 2.)

Cleaning expense will be either the weight per day multiplied by the cleaning cost per pound, or a percentage of the direct molding cost.

Under scrap: Insert here the percentage rate which your experience teaches you, will be satisfactory to cover the defective castings.

Extras: If any, such as machining, plating, enameling, galvanizing, etc., should be inserted here and the total cost shown in the estimate column.

Line marked total cost will be the total foundry cost for a specified quantity of castings. Profit is to be added at a proper percentage on the next line.

The next line is for freight, if this item is prepaid.

The line marked total sales will show the total selling price for the specified quantity of castings estimated.

The cost per pound is arrived at by dividing the total cost estimate by the number of pounds produced per day.

(For Discussion See Page 741)

Cost Methods in the Malleable Iron Industry

BY ROBERT E. BELT*, CLEVELAND, OHIO

1. In the malleable iron industry, the cost methods, which today are in use by more than three-fourths of the total number of producers, are those which have been formulated and promulgated by the industry's trade association. It is those methods, currently in use, which are here presented.

2. With respect to the principles which are followed to allocate indirect expense in the determination of job costs, they will be merely stated without entering into the underlying reasons for their use. Suffice to say, that they are the result of years of experience combined with thorough analysis and study.

3. Emphasis in this presentation will be put on the procedure in preparing a predetermined cost in advance of quoting and in preparing a cost on the completion of the order, in the event the order is received. The simplicity of the procedure and the small amount of clerical labor necessitated will be apparent as well as the dependability of the results. A great deal of thought has been given to ways and means of reducing the labor of cost-finding to the minimum consistent with accurate results. Much has been accomplished only recently along the lines of a formula, the make-up of which reflects all of the several basic principles of cost allocation which are considered necessary to obtain accurate and dependable results.

DIRECT COSTS

4. Our first step was to determine what the direct costs are in the production of malleable iron castings. By direct costs are meant those which can be charged directly to the job and recorded by pattern numbers. In malleable iron practice, such items of costs, on first analysis, are but four in number, namely, the labor operations of (1) molding, (2) coremaking, (3) grinding, and (4) straightening, or other finishing operations. The fact that these direct labor operations do not ordinarily comprise over 25 per cent of the total cost of production, clearly demonstrates the necessity of dependable bases for the allocation of so-called indirect costs.

5. If the basis of allocation, however, is the correct one, a

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NOTE: Paper presented before Cost Session of the Annual Convention of The American Foundrymen's Association, Milwaukee, Wis., May 7, 1937.

considerable part of the indirect costs can be applied to the job nearly as dependably as can the above-mentioned direct labor operations. This is true of the cost of metal in the casting, including melting, when yield is reckoned as a cost factor, and of the cost of cores when the weight of cores is reckoned as a cost factor. Direct labor and direct materials, therefore, comprise roughly 60 per cent of the total cost of production which narrows the element of error with respect to the allocation of the remaining 40 per cent of indirect costs.

INDIRECT COSTS

6. Under the head of indirect costs fall all costs of (1) molding, other than direct labor, (2) hard iron cleaning, (3) hard iron trimming, (4) annealing, (5) soft iron cleaning, (6) grinding and finishing, other than direct labor, (7) assorting and shipping, (8) drayage, (9) returns and allowances (cost less scrap value), (10) fixed plant charges (such as insurance, taxes, depreciation), and (11) administrative and selling expense.

ARRANGEMENT OF ACCOUNTS

7. The arrangement of the cost accounts, which the procedure advocates, follows the sequence of production and is arranged by departments. This is done to furnish information for managerial purposes and corresponds with units of operating responsibility. A secondary arrangement of the cost accounts, or divisions of costs, is by bases of application of indirect costs.

BASES OF APPLICATION OF INDIRECT COSTS

8. It will be seen from Table 1, the arrangement of the cost divisions of which is by bases of application, that the procedure is to apply metal, exclusive of metal loss, hard iron cleaning, annealing, soft iron cleaning, assorting and shipping, drayage, returns and allowances, and a proportion of fixed plant charges, on the basis of weight of good castings produced.

9. Metal loss, melting, one-half of molding indirect, and a proportion of fixed plant charges, are applied on the basis of weight of metal poured.

10. One-half of molding indirect, hard iron trimming, and a proportion of the fixed plant charges, are applied on the basis of molding direct labor.

11. The proportion of the fixed plant charges, which is applicable to the core department, is applied on the basis of core-

PROCEDURE IN DETERMINING (January -

	Totals	Weight of Good Cast- ings Pro- duced
Metal (not incl. Metal Loss)	\$22,140	22,140
Metal Loss	4,740	
Melting	12,600	
Molding Indirect	13,200	
Coremaking Indirect	6,720	
Hard Iron Cleaning	1,680	1,680
Hard Iron Trimming	2,640	
Annealing	12,360	12,360
Soft Iron Cleaning	1,920	1,920
Grinding and Finishing Indirect ...	2,400	
Grinding Wheels	1,680	
Assorting and Shipping	4,080	4,080
Drayage	720	720
Returns and Allowances	2,400	2,400
Fixed Plant Charges (a)	17,010	5,103
	106,290	50,403
Direct Labor Costs	29,040	
Manufacturing Cost	135,330	50,403
Administrative and Selling (a)(b) .	9,000	3,352
Total Cost	144,330	53,755
Pounds Metal Poured	5,018,220	53,755
Pounds Good Castings Produced .	2,400,000	+
Pounds Cores Used'	610,000	2,400,000
		=
Yield (2,400,000 ÷ 5,018,220) .	48.0%	\$2.240 per 100 lbs.

- (a) On basis of Normal Operations
(b) On basis of Manufacturing Cost

TABLE 1—LEFT PORTION OF FORM FOR PROCEDURE IN DETERMINING FACTORS OF INDIRECT COSTS

FACTORS OF INDIRECT COST
March, 1937)

Applied on the basis of					
Weight of Metal Poured (Yield)	Molding Direct Labor	Core-making Direct Labor	Weight of Cores Used	Combined Grinding and Finishing Direct Labor	Grinding Direct Labor Additional
4,740 12,600 6,600	6,600		6,720		
	2,640			2,400	1,680
1,701	6,804	1,701		1,701	
25,641	16,044	1,701	6,720	4,101	1,680
	18,000	4,800		G 3,840 F 2,400	
25,641	34,044	6,501	6,720	10,341	1,680
1,705	2,264	432	447	688	112
27,346	36,308	6,933	7,167	11,029	1,792
27,346	36,308	6,933	7,167	11,029	1,792
+	+	+	+	+	+
5,018,220	18,000	4,800	610,000	6,240	3,840
=	=	=	=	=	=
\$0.545 per 100 lbs.	201.7%	144.4%	\$1.18 per 100 lbs.	176.7%	46.7%

TABLE 1—RIGHT PORTION OF FORM FOR PROCEDURE IN DETERMINING FACTORS OF INDIRECT COSTS

making direct labor. Coremaking indirect is applied on the basis of the weight of cores used.

12. Grinding and finishing indirect, and the proportion of the fixed plant charges which is applicable to the grinding and finishing department, are applied on the basis of the combined grinding and finishing direct labor. Grinding wheels are applied on the basis of grinding direct labor.

13. Administrative and selling expense are applied on the basis of manufacturing cost.

14. With the foregoing bases of distribution in mind, an analysis sheet, such as that shown in Table 1, can be prepared from which the factors of indirect costs can be readily obtained.

15. To prepare a cost estimate, or to obtain the cost of any given job, it will be noted (from the figures used in Table 1 for illustrative purposes) that the factor to be applied to the weight of good production is \$2.24 per 100 lb.; the factor to be applied to the weight of metal poured is \$0.545 per 100 lb. of metal poured; the factor to be applied to molding direct labor is 201.7 per cent; the factor to be applied to coremaking direct labor is 144.4 per cent; the factor to be applied to weight of cores is \$1.18 per 100 lb.; the factor to be applied to the combined grinding and finishing direct labor is 176.7 per cent, and the factor to be applied to grinding direct labor is 46.7 per cent.

COST FORMULA

16. These several factors are then set up as a cost formula, Table 2, for convenient use in preparing a cost estimate or a final cost on completion of the job.

17. Clerical labor in cost calculations is materially lessened by the preparation of a yield table which gives, without further calculation, the cost at any given yield of all items which are applied on the bases of weight of good production and weight of metal poured.

18. The effect of yield on cost, which of necessity must be reckoned in malleable iron practice due to the wide variance in yield of different jobs, can be seen from Table 2. The difference, for example, as illustrated (which checks closely with practice), between a job with a 30 per cent yield and a job with a 65 per cent yield, due to this factor alone, is 97.8 cents per 100 lb., or \$19.56 per ton.

Table 2
COST FORMULA
 (January-March, 1937)

Weight of Good Production @:

Yield	30	40	50	60
	(Per 100 lbs. See Note)			
0	\$4.057	3.603	3.330	3.148
1	3.998	3.569	3.309	3.133
2	3.943	3.538	3.288	3.119
3	3.892	3.507	3.268	3.105
4	3.843	3.479	3.249	3.092
5	3.797	3.451	3.231	3.079
6	3.754	3.425	3.213	3.066
7	3.713	3.400	3.196	3.052
8	3.674	3.375	3.180	3.042
9	3.637	3.352	3.164	3.030

Molding Direct Labor @ 201.7%

Coremaking Direct Labor @ 144.4%

Cores Used @ \$1.18 per 100 lbs.

Grinding Direct Labor @ 223.4% (176.7% + 46.7%)

Finishing Direct Labor @ 176.7%

NOTE: Costs which are applied on basis of weight of good castings produced (\$2.240 per 100 lbs.) plus costs which are applied on basis of weight of metal poured (\$0.545 per 100 lbs. divided by percentage of yield).

COST SHEET

19. A cost formula having been thus set up, a clerk with a calculating machine can prepare a cost estimate or a cost sheet (Table 3) on the completion of the job in a surprisingly small amount of time. From three to five minutes is all the time that is ordinarily needed to prepare a cost on obtaining from the production department information on weights, on the piece prices which will be paid or have been paid for the direct labor operations, and the scrap loss, estimated or actual.

20. Errors in estimating can be spotted and the dependability of estimates greatly improved by comparing actual costs with estimated costs. A cost sheet of the form shown in Table 3 facilitates such comparisons.

21. The practice which is generally followed in the industry is to determine piece prices of direct labor operations, namely, molding, coremaking, grinding and finishing, as carefully for esti-

mating purposes as for production purposes. As the piece prices for estimating are presumed to be the ones actually paid, differences between an estimated and an actual cost are generally due principally to the factors of scrap and sprue. Naturally, differences in the piece prices which are used in an estimate and in the piece prices actually paid, as well as in estimated scrap loss and actual scrap loss are causes of inquiry to determine reasons and to locate responsibility.

Table 3

COST SHEET

Wt. per Casting 2.0	Wt. Sprue 7.0	Customer _____
Pcs. per Mold 4	Wt. Gross Mold 15.0	Pattern _____
Lbs. per Mold 8.0	Wt. Cores per Castg... 1.0	
	Estimate	Actual
Date	4/20/37	
Quantity (pieces)	2,000	
Good Molds to Make	500	
Scrap Loss (%)	6-2-2	
Molds to Make	556	
Metal to Pour (lbs.)	8,340	
Good Production (lbs.)	4,000	
Yield (Metal Poured)	48%	
Tonnage Costs	4,000 lbs. @ 3.375	\$135 00
Molding	522 Molds @ 6¢ = \$31.32 x 201.7%	63 17
Coremaking (5% breakage)	2,341 Cores @ 60¢ = \$14.05 x 144.4%	20 28
Core Weight	2,224 Cores @ 1# = 2,224 lbs. x \$1.18	26 24
Grinding	2,041 Pcs. @ 50¢ = \$10.21 x 223.5%	22 81
Finishing	2,041 Pcs. @ 20¢ = \$4.08 x 176.7%	7 21
Total Cost	\$ 6.87 per 100 lbs	274 71

Non-Ferrous Foundry Cost Methods

BY JAS. L. WICK, JR.,¹ YOUNGSTOWN, O.

Introduction

The writer was brought face to face with costs at the 1926 Detroit convention of the American Foundrymen's Association, and R. E. Belt was on the program. His fine contribution started us in intelligent cost finding. We went to him after his paper was given and said, "You have a job. Come to Youngstown and establish a system in our shop so that we will know what we are doing."

We have since refined his proceedings. Then when N.R.A. arrived it was my privilege to be very intimately associated with Mr. Tour and others as members of the cost committee of the Non-Ferrous Foundry Association for Industrial Recovery. We were given the assignment of determining what constituted "selling below cost". We developed the Cost Accounting and Estimating System which I am presenting here. You will note that it is quite like Mr. Grede's gray iron system, quite like Mr. Belt's malleable system as presented at this meeting and it applies just as well to steel.

The purpose of this cost system is to provide a satisfactory system for those wishing to install a system or to change over their present system and at the same time provide a standard system for estimating purposes. It is understood that the minima under this system will not recover full actual costs until such time as volume of business returns to normal and unless the cost of doing business (Item I of the system given below) is included in the costs.

The system is recommended for the smaller foundries and the means for more detailing of it for larger foundries is indicated throughout. Whenever a material change occurs in wage rates, material or supply prices or overhead expenses new averages of departmental costs and new burden rates should be figured and from then on these new departmental costs used in estimating. All labor shall be estimated on the basis of paying wage rates at least equal to the average wage rates being paid in the territory for the class of work performed.

Where some of the departments shown are not operated in the plant in question, they, of course, need not be incorporated in the figures.

¹ President, Falcon Bronze Co.

NOTE: Presented before Cast Session of 41st Annual Convention, Milwaukee, Wis., May 7, 1937.

*The System***I. Cost of doing Business (Profit and Loss)**

The following are considered as profit and loss items and are* not figured as a part of costs but come out of apparent profits before any real profit is realized on business done:

11. Interest.
12. Income tax.
13. Dividends on stock or bonds.
14. Research and development expense.
15. Bad accounts.
16. Declines in market value of inventory.
17. Special sales or advertising campaigns.
18. Group insurance.
19. Inoperative plant.
20. Unabsorbed overhead.

II. Fixed Overhead

Amount of fixed overhead to be distributed and absorbed is based upon relation of total business to the normal amount of business.

21. Rent.
22. Building maintenance and watchman.
23. All taxes except income taxes and sales taxes.
24. Fire insurance and all other insurance (except workmen's compensation, group life and health unemployment insurance).
25. Depreciation of buildings.
26. Depreciation of equipment.—Same basis as for buildings but at average flat rate of not less than 10 per cent.
27. Administration and office expense, directors fees, dues, subscriptions, legal expense, auditing expense, etc.
28. Sales expense, commissions, advertising.

The basis for depreciation shall be cost of reproduction new including freight and installation, based on an actual accurate appraisal. In the case of plant and equipment acquired at an abnormal price the basis shall be the fair replacement value of such assets.

* In our company all but 12, 13, 16 and 19 are included in "Fixed Overhead."

<i>Type of Construction</i>	<i>Minimum Depreciation Per Cent</i>
Brick, concrete or steel frame.....	3
Masonry with frame interior.....	4
Frame	4½
Corrugated Iron.....	10

Where classified rates are used, the minimum rates of depreciation shall not be less than the rates listed in the Report of the Bureau of Internal Revenue dated January 1931 entitled "Depreciation Studies." The complete writing off of plant and equipment by the use of higher rates of depreciation or otherwise does not create an exemption from the calculation of depreciation for cost purposes.

The least portion of fixed overhead which must be absorbed is that percentage of the total fixed overhead that the current volume of business in pounds of good castings produced during the preceding three calendar months bears to the "normal" volume of business in pounds for the plant. The "normal" volume of business in pounds for any plant is considered as 60 per cent of that plant's best six consecutive months production since January 1, 1924 (ten years). If, however, added capacity has been made by such plant since the period of the best six consecutive months of production after January 1, 1924 then the "normal" volume of production shall be increased by the ratio of increase in plant facilities. Such ratio of increase shall be determined by the percentage of increase in plant investment. Likewise if any facilities in use during the period of the best six consecutive months after January 1, 1924 have been sold or otherwise disposed of then the "normal" volume of production shall be decreased by the ratio of decrease in plant investment.

Having determined the percentage as above then that percentage of fixed overhead must be absorbed in the various departments.

Items 21 to 25 above are preferably distributed to departments on basis of floor space in each department. Item 26 on basis of value of equipment installed and items 27 to 29 on basis of total payroll dollars or preferably direct labor man hours in each department. If individual distribution is not desired in any plant it is permissible to distribute the total "fixed overhead" (total of items 21 to 29 inclusive adjusted for current volume of business)

to the departments on basis of total payroll dollars or preferably total labor man hours in each department.

III. Operating Overhead

The entire operating overhead must be distributed to and absorbed in the various departments with account numbers as indicated below:

31. General plant labor.
32. Plant supervision and plant office help.
33. Fuel and power, supplies and tools in boiler and engine rooms.
34. General supplies.
35. Workmen's compensation insurance.
36. Loss on product scrapped, including returns from customers (Not less than 5 per cent).
37. Laboratory.

The total operating overhead is distributed on the basis of total payroll dollars or, preferably total labor man hours in each department.

IV. Metal

Metal cost equals initial metal cost per pound plus metal expense per pound times weight of casting plus per cent of shrinkage.

41. Raw metals, purchased scrap, and alloys including freight and cartage. All at current market price for grade of metal used.
42. Metal Expense:
 - Unloading, sorting and storing labor.
 - Sampling inspection and analysis expenses on incoming metals. Total metal expense item 42, for a period of one year divided by pounds of metal gives average metal expense per pound.
43. Shrinkage (based on type of metal used, etc., not less than 5 per cent of metal value, item 41).

V. Melting

Melting cost per pound of metal equals total of item 51 plus item 52 divided by pounds of metal used under IV.

51. All labor in the melting department:
 - Handling metals and scrap, making up charges, melting, repairing furnaces, metallurgists and chemists time spent on metals.

52. Burden.—All other items chargeable to the melting department.

- (a) Melting fuel including freight and cartage and including power for electric melting.
- (b) Supplies such as fluxes, crucibles, fire bricks, fire clay, and tools such as crucible tongs, shanks, shovels, scoops, etc.
- (c) Costs of analyses and tests made on metals.
- (d) Share of operating overhead, (based, preferably on labor hours, or payroll dollars).
- (e) Share of fixed overhead, (based, preferably on labor hours, or payroll dollars).

VI. Molding

Molding cost equals direct labor plus burden plus direct materials.

61. Direct labor such as molders, apprentices, molders helpers, and any other labor which can be directly charged to individual jobs such as skin drying, finishing, core setting, etc.

62. Burden—All other items except direct materials chargeable to molding department.

Burden shall be proportioned against each job on basis of either total direct molding labor cost in dollars or, preferably direct molding labor, total in man hours.

- (a) All labor not directly chargeable to individual jobs such as:—preparing molding sand, mixing facing; transporting sand, castings, patterns, flasks, boards, supplies, etc.; repairing equipment in the department; foremen and clerks, repairing patterns not chargeable to customer.
- (b) Supplies and tools such as molding sand, including freight and cartage, facings, sea coal, parting, plumbage, shovels, riddles, brushes, reamers, clamps, gaggers, chaplets, nails, air hose and fittings, etc. Pattern and flask repair parts and repair parts for equipment.
- (c) Fuel and power.
- (d) Share of operating overhead, [based on direct labor (item 61) plus indirect labor (item 62a) either, preferably man hours, or payroll dollars].

- (e) Share of fixed overhead, [based on direct labor (item 61) plus indirect labor (item 62a) either, preferably, man hours, or payroll dollars].
- 63. Direct materials chargeable to individual jobs such as special flasks, match plates, etc.

VII. Core Making

Cost of cores equals direct labor plus burden plus direct materials.

- 71. Direct labor such as coremakers apprentices, coremakers helpers, and any other labor which can be directly charged to individual jobs such as venting, blacking, pasting, assembling, filing, rubbing, coating, gauging, etc.
- 72. Burden:—All other items except direct materials chargeable to the Coremaking Department. Burden shall be apportioned against each job on basis of either total direct core labor in dollars or, preferably direct core labor in man hours:
 - (a) All labor not directly chargeable to individual jobs such as preparing core sand, mixing, tending core ovens, transporting core sand, core boxes, repairing core boxes not chargeable to customer, repairing equipment, foremen and clerks.
 - (b) Supplies and tools such as core sand including freight and cartage, binders, core compounds, core oil, shovels, riddles, brushes, rammers, core plates, core wire, core rods, nails, core wax, etc.; core box repair parts and repair parts for equipment.
 - (c) Fuel and power.
 - (d) Share of operating overhead, (based on direct labor, item 71, plus indirect labor, item 72(a), either, preferably man hours, or payroll dollars).
 - (e) Share of fixed overhead, [based on direct labor, item 71, plus indirect labor, item 72(a), either, preferably man hours, or payroll dollars].
- 73. Direct materials chargeable to individual jobs such as special core rods, boxes, driers, etc.

VIII. Cleaning, Trimming, Rough Grinding and Sand Blasting Department

Cost per job in this department equals direct labor plus burden plus direct materials.

81. Direct labor which can be directly charged to individual jobs such as for cutting off gates and risers, tumbling, sand blasting, pickling, removing cores, grinding, filing.
82. Burden:—All other items except direct materials chargeable to this department. Burden shall be apportioned against each job on basis of either total direct labor cost in dollars or, preferably direct labor total man hours.
 - (a) All labor not directly chargeable to individual jobs such as those indicated under direct labor and repairing equipment, clean up labor, foremen, clerks, transportation of castings and scrap.
 - (b) Supplies and tools such as sand blast sand, steel shot, grinding wheels, band saws, hack saws, files, pickling acids, equipment repair parts, etc.
 - (c) Fuel and power.
 - (d) Share of operating overhead, [based on direct labor, item 81 plus indirect labor 82(a) either, preferably man hours, or payroll dollars].
 - (e) Share of fixed overhead, [based on direct labor, item 81, plus indirect labor, item 82(a), either man hours (preferably) or payroll dollars].
83. Direct materials chargeable to individual jobs such as special cutters, band saws, tools, wire brushes, cut off wheels, trimming dies, etc.

IX. Machining, Polishing and Finishing Department

Cost per job in this department equals direct labor plus burden plus direct materials.

91. Direct labor which can be directly charged to individual jobs such as drilling, tapping, turning, boring, grinding, polishing, buffing, pickling, electro cleaning, plating, coloring, etc.
92. Burden:—All other items except direct materials chargeable to this department. Burden shall be

proportioned against each job on basis of either direct labor cost in dollars, or, preferably direct labor total in man hours:

- (a) All labor not directly chargeable to individual jobs such as those indicated under direct labor and also repairing equipment, clean up labor, transportation of castings, foreman, clerks, etc.
 - (b) Supplies and tools such as tool bits, drills, taps, reamers, polishing grit, wheels, and compounds, cleaning compounds, acids, plating supplies and anodes, hangers and supports, equipment repair parts, etc., not chargeable to individual jobs.
 - (c) Fuel and power.
 - (d) Share of operating overhead, [based on direct labor, item 91, plus indirect labor, item 92(a), either, preferably man hours, or payroll dollars].
 - (e) Share of fixed overhead, [based on direct labor, item 91, plus indirect labor, item 92(a), either, preferably man hours, or payroll dollars].
93. Direct materials chargeable to individual jobs such as special cutters, tools, dies, grinding and polishing wheels, plating racks, lacquers, paints.

X. Inspection—Packing and Shipping Department

Cost per job in this department equals direct labor plus burden plus direct materials.

- 101. Direct labor which can be directly charged to individual jobs such as gauging, pressure testing, wrapping separately, making special cases, etc.
- 102. Burden:—All other items except direct materials chargeable to this department. Burden shall be proportioned to each job on basis of either total direct labor in dollars or, preferably direct labor total men hours:
 - (a) All labor not directly chargeable to individual jobs such as those indicated under direct labor and also repairing equipment, clean up labor, transportation, of castings, marking and billing, foremen, clerks, truck drivers.

- (b) Supplies and tools such as bags, boxes, crates, cartons, paper, etc., not chargeable to individual jobs.
 - (c) Fuel and power.
 - (d) Share of operating overhead, [based on direct labor 101 plus indirect labor, item 102(a), either, preferably man hours, or payroll dollars].
 - (e) Share of fixed overhead [based on direct labor, item 101, plus indirect labor, item 102(a), either, preferably man hours, or payroll dollars].
103. Direct materials chargeable to individual jobs such as special gauges, testing devices, boxes, cartons, crates, containers, etc.
- Delivery expense.

Mention should be made that as a further refinement of the cost system, *Service Departments* may be established in those foundries in which such departments are operated or wish to be operated. The costs of such departments are collected in the same manner as the *operating departments* but at the end of the month the service costs of such departments are distributed to the *operating departments* in proportion to the amount of such service received during the month. This item then becomes a portion of the *operating departments* overhead or burden.

Likewise in the handling of the costs of a *mixed department*, that is, a department doing both *operating* and *service* work, the amount of *service* costs are segregated at the end of the month and distributed to the *operating departments* the same as in the case of pure *service departments*.

Non-Ferrous Cost Methods

An Example of Applying System

An example of the foregoing cost estimating system as applied to a non-ferrous foundry having about \$25,000 sales for a production of about 82,000 pounds of miscellaneous sand castings, other than aluminum, for the preceding year is given below:

I. Cost of Doing Business (Profit and Loss) for the year:

ACCOUNT No.	NAME	AMOUNT	
11	Interest on Investment.....	\$600.00	(6% on \$10,000)
12	Interest on Debt.....	300.00	(6% on 5,000)
13	Dividends on Stocks or Bonds..	100.00	
14	Research and Development Ex- pense	350.00	
15	Bad Accounts.....	360.00	
16	Decline in Market Value		
17	Special Advertising.....	50.00	
Cost of doing business (\$25,000).....			7.04%

II. Fixed Overhead—for the year:

ACCOUNT No.	NAME	AMOUNT	
21	Rent	\$1,000.00	
22	Building Maintenance.....	600.00	
23	Taxes	150.00	
24	Insurance	75.00	
25	Depreciation of buildings.....	100.00	
26	Depreciation of equipment....	700.00	
27	Administration	2,000.00	
28	Sales	500.00	
Total			\$5,125.00
"Normal" business is determined as follows:			
Best consecutive 6 months' production since Jan. 1, 1924.....			100,000 lbs.
Investment in Plant and Facilities dur- ing above period.....		\$ 8,000.00	
Subsequent added potential capacity...		2,000.00	
Present Investment.....		\$10,000.00	
Per cent increase in investment.....		25%	25,000 lbs.
Adjusted Capacity.....			125,000 lbs.
Normal 6 months' production			
60% of Capacity.....			75,000 lbs.
Actual production preceding 6 months..			41,000 lbs.
Rate of operation (% of Normal).....			54.6%
<hr/>			
54.6% of Fixed Overhead \$5,125 to be absorbed			\$2,798.25
<hr/>			
Loss on Fixed Overhead due to low volume business.....			\$2,326.75
(9.3% of Sales)			

III. Operating Overhead for the year:

ACCOUNT NO.	NAME	AMOUNT
31	General Labor	\$ 600.00
32	Plant Supervision	1,800.00
33	Heat	100.00
34	Supplies	75.00
35	Compensation	150.00
36	Loss on scrap.....	1,000.00 (4% of \$25,000 Sales)
37	Laboratory	100.00
Total		\$3,825.00

The portion (\$2,798.25) of Fixed Overhead is absorbed in the various departments on the basis of payroll dollars, preferably direct labor, in each department. The entire Operating Overhead is absorbed on the same basis, as follows:

DEPT.	PAYROLL	% OF TOTAL	SHARE FIXED OVERHEAD	SHARE OPERATING OVERHEAD
V Melting	\$ 300.00	5.0	\$ 139.91	\$ 191.25
VI Molding	3,000.00	50.0	1,399.12	1,912.50
VII Core Making	750.00	12.5	349.78	478.12
VIII Cleaning	750.00	12.5	349.78	478.12
IX Finishing	750.00	12.5	349.78	478.12
X Shipping	450.00	7.5	209.88	286.89
TOTAL	\$6,000.00	100.0	\$2,798.25	\$3,825.00

IV. Metal for the year:

ACCOUNT NO.	NAME	AMOUNT
41	Raw Metals	\$7,200.00 (82,000 lb. metal)
42	Metal Expense	300.00
43	Shrinkage	360.00 (5% of \$7,200)
Total		\$7,860.00
Metal Expense Total.....		660.00
Metal Expense per pound....		\$.008

V. Melting for the year:

ACCOUNT NO.	NAME	AMOUNT
51	Labor	\$ 300.00
52 (a)	Melting Fuel	150.00
(b)	Supplies	50.00
(c)	Analyses and Tests.....	50.00
(d)	Share Operating Overhead.....	191.25
(e)	Share Fixed Overhead.....	139.91
Total		\$ 881.16
Cost of melting per pound....		\$.0108

VI—Molding; VII—Coremaking; VIII—Cleaning.

DEPARTMENT	VI—MOLDING		VII—COREMAKING		VIII—CLEANING	
	ACCT.	AMT.	ACCT.	AMT.	ACCT.	AMT.
Direct Labor	61	\$2,400.00	71	\$ 650.00	81	\$ 650.00
Burden	62		72		82	
Indirect Labor	(a)	600.00	(a)	100.00	(a)	100.00
Supplies	(b)	175.00	(b)	70.00	(b)	120.00
Fuel and Power....	(c)	25.00	(c)	50.00	(c)	20.00
Share Op. Overhead.	(d)	1,912.50	(d)	478.12	(d)	478.12
Share Fix. Overhead	(e)	1,399.12	(e)	349.78	(e)	349.78
Direct Materials....	63	200.00	73	100.00	83	50.00
TOTALS.....		\$6,711.62		\$1,797.90		\$1,767.90

IX—Finishing; X—Shipping.

DEPARTMENT	IX—FINISHING		X—SHIPPING	
	ACCT.	AMT.	ACCT.	AMT.
Direct Labor.....	91	\$ 650.00	101	\$ 250.00
Burden	92		102	
Indirect Labor.....	(a)	100.00	(a)	200.00
Supplies	(b)	200.00	(b)	400.00
Fuel and Power.....	(c)	50.00	(c)	30.00
Share Op. Overhead.....	(d)	478.12	(d)	286.89
Share Fixed Overhead.....	(e)	349.78	(e)	209.88
Direct Materials.....	93	125.00	103	120.00
Delivery Expense.....			104	100.00
TOTALS.....		\$1,952.90		\$1,596.77

Departmental Burdens on Direct Labor

The departmental burdens on direct labor in each of the above departments then is the sum of (a) plus (b) plus (c) plus (d) plus (e) and these are applied on the basis of direct labor in each case, as follows:

BURDEN	BURDEN PER DOLLAR DIRECT LABOR, PRE- FERABLY PER HOUR OF DIRECT LABOR	
	DIRECT LABOR PAYROLL	
Molding	\$4,111.62	\$2,400.00
Core Making	1,047.90	650.00
Cleaning	1,067.90	650.00
Finishing	1,177.90	650.00
Shipping	1,126.77	250.00
		\$1.71
		1.61
		1.64
		1.81
		4.51

Summary of Business

CLASS	NAME	AMOUNT
I	Cost of Doing Business.....	\$ 1,760.00
II	Unabsorbed Fixed Overhead.....	2,326.75
III	Unabsorbed Operating Overhead.....	
IV	Metal.....	7,860.00
V	Melting.....	881.16
VI	Molding.....	6,711.62
VII	Coremaking.....	1,797.20
VIII	Cleaning.....	1,767.90
IX	Finishing.....	1,952.90
X	Shipping.....	1,596.77
Total Actual Cost.....		\$26,655.00
Sales Price.....		25,000.00
NET LOSS FOR YEAR.....		\$ 1,655.00

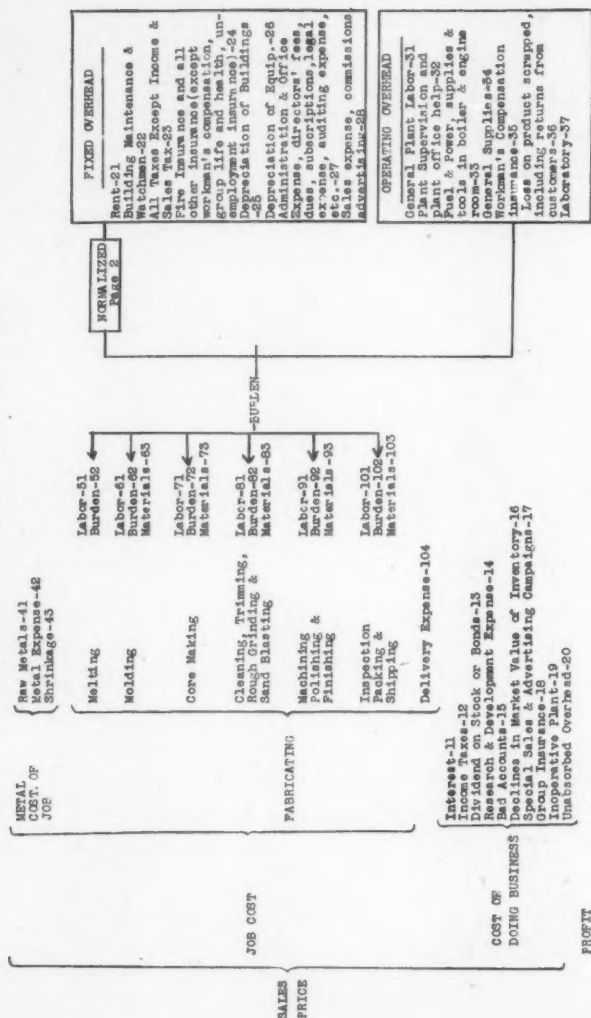
FIG. 1—FORM FOR ESTIMATE OF SALES COST.

DATE.....		ESTIMATE OF SALES COST		BY.....	
Customer.....	Our Alloy.....				
Address.....	Copper.....	Lbs.	\$		
Delivery.....	Zinc.....	Lbs.	\$		
Pattern No.....	Lead.....	Lbs.	\$		
Drawing No.....	Terms.....	Lbs.	\$		
Part Name.....	Phos.....	Lbs.	\$		
No. Per. Required.....	Nickel.....	Lbs.	\$		
Pos. per Flask.....	Shrinkage.....	Lbs.	\$		
Mfg. Wt. Per Pos.....	Ship Wt. Per Pos.....				
Mach. Patt.....	Loose Patt.....				
Green Sand.....	Dry Sand.....				
Flask Size.....	Cope.....	Drag.....			
		Total Cost Metal per lb.			

SUMMARY	ESTIMATE	ACTUAL
Melting Labor.....	Lbs. \$	
Burden.....	Lbs. \$	
Molding Labor.....	Hrs. \$	
Burden.....	Hrs. \$	
Core making Labor.....	Hrs. \$	
Burden.....	Hrs. \$	
Machining Labor.....	Hrs. \$	
Burden.....	Hrs. \$	
Patterns, flasks, plates, etc. Labor.....	Hrs. \$	
Burden.....	Hrs. \$	
Material.....	Lbs. \$	
Clean & Shake Out Labor.....	Lbs. \$	
Burden.....	Lbs. \$	
Sand Blasting Labor.....	Lbs. \$	
Burden.....	Lbs. \$	
Royalties.....	Lbs. \$	
Freight and Ship. Expense.....	Lbs. \$	
Special Deoxidizer & Fluxes.....	Lbs. \$	
Chills.....	\$	
Chemicals Analyses or Physical Test.....	\$	
Crating, cartons, etc. for shipping.....	\$	
Tools, dies, gauges, etc. for finishing.....	\$	
Ship Wgt.....		
Mfg. Cost per Lb.....		
Metal Cost per Lb.....		
Total Net Cost.....		
Profit (allow for Hazard).....		
Selling price per Lb.....		

REMARKS:
Earliest Shipment After Receipt of Order.....
Earliest Shipment After Receipt of Pattern.....

FIG. 2—NON-FERROUS FOUNDRY INDUSTRY FLOW SHEET.



Proceeding of Session on Foundry Costs

41st Annual Convention, Milwaukee, Wis., May 5, 1937.

Presiding: SAM TOUR, Chairman, A.F.A. Foundry Cost Committee and Vice President, Lucius Pitkin, Inc., New York, N. Y.

CHAIRMAN TOUR: The Cost Committee of the A.F.A. arranged this meeting for the purpose of having presented a number of discussions of cost estimating as applied to the different branches of the foundry industry. Foundry costs have been the subject of A.F.A. discussions and papers for many years.

We will open the meeting by calling on Mr. R. E. Belt of the Malleable Founders' Society, Cleveland, Ohio, to talk on "Malleable Foundry Cost Methods."

... Mr. Belt presented his paper (See Pages 720 to 726).

CHAIRMAN TOUR: The foundry industry is indebted to Mr. Belt for quite a number of things in connection with cost accounting in the industry, and he has now given us more. I wish to call attention to his remark that if you once get set, you can calculate a logical cost estimate on a job in from three to five minutes. If a job is not worth spending three to five minutes on before being accepted, then that job should not be worth getting at all.

Mr. Belt, can you give some estimate of the time required for a foundry to develop the data for this cost formula so as to do this work in from three to five minutes. Can you clarify the setting up of this cost system and remove any fear as to its being an enormous job?

MR. BELT: It is presumed that every plant has a certain amount of cost information. They are recording certain costs; they have a record of the cost of labor; they have a record of the cost of materials. Breaking down the pay roll into classifications by departments involves only a slight amount of additional labor. Breaking down purchases of material by departments, or by cost divisions, requires only a small amount of additional labor. This merely involves a rearrangement of the cost accounts; often it entails no additional clerical labor to what the company is already employing. So there is not much added expense in that connection.

There is, of course, an added expense in getting a job cost and getting it dependably, compared with having no cost information. That goes without saying. If the labor operations of molding, core making and grinding are on a piece work basis, you have the foundation of the cost of that given job. And if the piece rates are determined as carefully at the time of estimating as they are ordinarily at the time the job goes in the sand, you are going to get an estimate that is dependable,—just as dependable as your ultimate cost,—and certainly it is the only safe procedure for anyone to follow.

To prepare an estimate, even only mental, one has to have in mind certain factors of production, and when those factors, those rates and

those weights are turned over to a clerk to figure the direct costs and to add the overheads, you get a complete cost. So the three to five minutes that are required to perform the calculations in obtaining the cost is not the total time that is needed, but is all that is needed, providing your production department or whoever is responsible for setting rates and establishing weights has determined that information and turns it over to the cost department.

J. J. WITENHAFFER¹: We have been using Mr. Belt's system of cost finding for the past six years and find that a clerk will figure eighty to ninety estimates per day. It is our practice to determine a standard cost on each job before the job is placed in our foundry. All standard piecework rates are recorded on our work order, that is, the rate to be paid for molding, coremaking, grinding, chipping, straightening, or any other special operation that has to be performed before castings can be shipped.

Whenever any department cannot meet the standard rate set, they immediately notify their timekeeper who secures an additional allowance for the operation. This additional allowance is shown on the employee's time card in red and is totaled each day to advise the management that they have lost a certain amount of money due to a certain cause where standards could not be maintained. If the operation is necessary and was omitted from the original estimate, this standard is recorded on our production records and the next time an order is received, the sales department is advised that they must secure an increase in selling price from our customer. In such a case whenever we know that the pattern is a job that repeats monthly, our sales department notifies our customer that his next order will be at a higher price, also stating the reason for the increase.

Our cost department totals these extra allowances by department, then applies the overhead factor to arrive at the total loss each day, thereby preventing a loss to continue forever where it can be stopped either by better foundry practice or being paid by the customer for the additional operation omitted in the original estimate.

PETER E. RENTSCHLER²: As a matter of information, I would like to know by what reasoning this molding indirect is split on the basis of weight of metal poured and direct labor. Is there any particular reasoning behind that, or is it just an arbitrary decision?

MR. BELT: Within the past three months we made a change in that respect. Up until recently the recommended practice in the industry was to apply all of the indirect expense of the molding department on the basis of the weight of metal poured. We gathered figures from eight companies—an analysis of the indirect cost of the molding department, in fact, every cost of that department other than direct labor. We obtained the viewpoints of those eight companies as to whether a given item under that general head bore a closer relation to weight of metal poured or to the molding direct labor, and rather oddly, there was quite a fair accord of opinion that a substantial part of the indirect expense of the molding department, indirect labor, sand, facing, etc., bore a closer relation to

¹ Office Manager, The Lake City Malleable Co., Cleveland, O.

² President, Hamilton Foundry & Machine Co., Hamilton, O.

direct labor (hours or dollars) than to weight of metal poured. The consensus of opinion indicated that about fifty per cent of that group of costs went with weight and about fifty per cent went with direct labor. That is more or less arbitrary, but the feeling is that applying a part of the expense on the basis of weight and a part on the basis of direct labor gives better results than applying all to direct labor.

It will be noted we are not using the hour distribution, that is, the hours of direct labor, in any instance. Though we realize that hours give a dependable basis, it is a little more difficult and adds to the clerical labor somewhat to determine hours for overhead distribution, and as the industry has been accustomed for years to the direct labor basis in dollars, we deem it advisable to continue to use dollars rather than hours.

MEMBER: Mr. Belt, in Table 2 of your paper, what are the zero to nine figures in the first column to the left? What do those different 1, 2, 3, 4 stand for?

MR. BELT: That is yield. The top figure of the second column is thirty per cent. Then go down the second column and checking with the left hand column it will be seen that thirty per cent would be 4.057; thirty-one per cent would be 3.998, and so on. It is just a convenient way of stating the cost factor that goes with any given percentage of yield. I think you will readily see the advantage of a formula of that sort because the calculation can be made directly from this chart. In fact, it is the calculation. If your unit is per hundred pounds, on determining the yield you turn to the table and get the cost that goes with that given yield.

CHAIRMAN TOUR: If there are no other questions, we will thank Mr. Belt for this very able presentation and for his thoughtfulness in arranging to have his discussion mimeographed in advance. We will now consider gray iron foundry cost methods, which will be presented by Mr. W. J. Grede of the Liberty Foundry Company, Milwaukee.

MR. GREDE: When the Chairman first asked me to report, he asked me to report as a member of the GRAY IRON FOUNDERS' SOCIETY on our recent publication, "The Simplified Cost System," and it was not until the present program was printed that I realized that the Cost Committee session had regained the status of a regularly accepted A.F.A. session and that I might be expected to produce a paper.

I am going to extemporize and just bring you first a report from the GRAY IRON FOUNDERS' SOCIETY on its most recent cost publication, and I will try to intersperse in my remarks some interpretations of the cost estimating procedure that is outlined.

. . . *For the Gray Iron Founders' Society Cost System, as presented by Mr. Grede, see pages 705 to 719.*

I am a member of the GRAY IRON FOUNDERS' SOCIETY committee, an operating foundry man, and interested in the development in our industry of some uniform method of calculating costs. This problem is a little more difficult in the gray iron industry than it is in the malleable iron industry because, in the first place, of the large number of units that there are in the gray iron foundry industry, and, secondly, because we have a much wider range of work in size and weight. I think that also is the reason why we do not have more gray iron foundries more vitally

interested in uniform cost keeping. But I think that unless we do follow some reasonably accurate method of calculating our costs, not only before quoting, but after running the job, we are going to face a period somewhat like we enjoyed a few years ago, known as "profitless prosperity."

Before discussing our most recent publication, I would like to give you just a little history of cost accounting in the gray iron industry.

In 1929, the GRAY IRON INSTITUTE published a rather comprehensive cost system. The development of that system was brought about through groups from various parts of the country with different schools of thought on how certain elements of cost should be handled. We found that there was an opinion rampant in the industry that there was no uniformity, that every gray iron foundryman had a different method of figuring costs. We were quite surprised to find that there were a great many elements in gray iron cost keeping that were quite uniform, due in large part to the splendid work of the A.F.A. Cost Committee prior to this time.

There are certain definite things that we are still quarreling about, but we found the fundamental departments—melting, molding, core making and cleaning—were rather uniformly accepted. Cleaning cost was one of the controversial points, and was applied in different ways by different groups. We had one group applying cleaning cost on the basis of direct molding labor, that is, cleaning cost as a percentage of direct molding labor. Another school of thought was applying it on a tonnage basis. I was glad to hear Mr. Belt's answer to Mr. Rentschler's question as to his division on the indirect molding costs.

We found the advocates of the per pound cleaning cost application saying that the indirect molding costs were applied to the direct molding labor cost, and that created certain inequalities because some of those indirect costs fluctuated with the tonnage rather than with the labor, and they advanced that argument for saying that they use the tonnage basis for cleaning costs, realizing that there were some cleaning costs that fluctuated with the direct molding labor rather than the tonnage, but the inequalities in each balanced the other.

That first committee, under the leadership of John Carter, published this rather complete system² and the only point on which we could not reach complete agreement was the question of cleaning costs, and so the system which recommended direct cleaning costs—that is, calculating the cleaning cost per casting on a direct labor basis in the cleaning room—was the most accurate, and for those who wished to get complete accuracy was the most advisable program to use.

Then we recommended, as an alternate, either the percentage of direct molding labor basis or the tonnage basis in the cleaning room.

In presenting that system² to the A.F.A. convention in 1930, the discussion brought out that there was no calculation made for yield such as Mr. Belt made in the malleable, and in our present publication for the sake of simplicity we have again avoided that calculation. It is not a difficult calculation to make; I would certainly recommend it for accuracy.

If there was anything to criticize in this first publication,² it would

² A Standard Cost System for Gray Iron Foundries, Transactions A.F.A. Vol. 38 (1930) pp. 577-623.

be the detail; for the first publication of a uniform system, it contained a considerable amount of detail. The detail was necessary for accurate costing, but it did complicate the question of uniform acceptance.

The next step in the gray iron cost program came with the N.R.A., and the establishment of a Code Authority and the regulation of selling below cost. The Code Authority felt that something more simple than the standard published system was necessary to impose regulations in that regard, and so in August of 1934, the Code Authority published a pamphlet, "Uniform Cost and Estimating System for the Gray Iron Foundry Industry," which was followed with two supplemental bulletins.

Of course, you know the history of the N.R.A., and it is not necessary for me to dwell on that point because before the system could be adopted or imposed on the industry, the N.R.A. had fallen by the wayside.

This N.R.A. publication brought no new development except possibly the recognition—or more definite recognition, I should say—of the calculation to normal. It recognized as normal 65 per cent of your best six month's production, from January 1, 1924 to January 1, 1934, multiplied by two to bring it to an annual basis.

On cleaning costs, this publication again recommended that the most accurate method was direct cleaning costs, but stated that for the purpose of determining whether castings had been sold below cost or not, they would accept either the tonnage basis or the percentage of direct molding labor basis.

After the N.R.A. was dissolved and the Code Authority disbanded, there was a feeling on the part of the officers of the revamped GRAY IRON FOUNDERS' SOCIETY that there was a definite need for a simple system. You must realize that in the gray iron industry the largest number of our units are smaller, on the average, than they are in the malleable iron industry where uniformity is much easier of accomplishment because you are dealing with larger units and a fewer number of them.

So we published, in July 1936, the "Simplified Cost System." It was called at that time "Simplified Cost System and Foundry Business Record," because we incorporated with the analysis of cost keeping a few bookkeeping forms to describe how to accumulate these costs, and then we proceeded to explain how to distribute them on a much simpler basis. We had fewer accounts, fewer divisions of accounts, but it was fundamentally approximately the same program that was in our original publication,—a sort of a condensation which can be expanded to most any size that might be required for your plant.

... (For the "Simplified Cost System" see pages 705 to 719.)

We have included some special journal sheets (pages 4-7), a combination pay roll and pay roll distribution sheet (pages 8-9), a recapitulation of cost data from the general data assembled to give the cost of melted metal and departmental overhead (page 10), and a cost estimating sheet (page 14).

The cost estimating sheet (page 718) is based on a molder's day's work, whether it was because of the fact that most members of the committee were using a molder's day's work as the basis or whether because that is the most generally accepted method in the gray iron industry, I am not prepared to say definitely, but what basis is used

for estimating is not necessarily important; you can use a hundred pounds, you can use a day's work, you can use a hundred molds or you can use one mold.

But we have provided for estimating on a molder's day basis. It has been the practice in some gray iron foundries to calculate profits instead of on a percentage basis on a per molder's day basis, and this form lends itself to that method of calculation.

We have provided for the various methods of figuring cleaning costs, either as a percentage of the molding direct labor, or per pound, or direct. We have, on the estimating sheet, separated the cleaning expense so that it can be made a separate calculation; this being done in order to encourage expansion of the system as soon as it has been adopted in a small foundry, so as to encourage and make it easier to transpose the system later into a direct cleaning cost system which we strongly recommend as the most accurate.

We have not made any provision for calculation on the basis of yield though we recognize that it has considerable merit.

There is also the method of figuring core costs on the basis of weight of core material. While in use by some gray iron foundries for some time—it is gaining more and more recognition—there is no mention of it in this publication, but I offer it to you as an addition that can be made. There is nothing in these forms or in this system that will not permit that extension if you desire.

Our final sheet is the flow chart (page 717), a copy of which was displayed at the Cost Committee meeting of the A.F.A. in Detroit in 1936. It is a very effective way of showing on one sheet the application of the various elements of cost.

I think as the publication is prepared it is very readily understandable, and as a member of the GRAY IRON FOUNDERS' SOCIETY, I urge upon all gray iron foundries the adoption of this method or some elaboration of it, but along these fundamental lines so that we can get more uniform acceptance of a standardized method. Once we have that, we can proceed to some of the refinements that are developing in Mr. Belt's program.

As a word of caution before closing, I would like to stress the importance of not only accumulating proper cost figures and transposing them to your estimating sheet, but also the necessity for making some accurate estimates on the direct items of cost. You notice I said "accurate estimates." I appreciate that there is a considerable amount of estimating, but I expect that a large part of the variation in pricing (and you know there is plenty of it!) comes from improper estimating as well as improper cost keeping.

Now to summarize the estimating sheet again, I would like to say that we have provided for accumulating all the metal costs on the basis of per pound of good castings, including the conversion or melting cost. We have provided a separate calculation for the alloys included. They could be included in your lump sum metal cost, but we put that in there especially so that some of you would not overlook it.

The molding price, if it is a piece work shop, or in a day work shop, the cost of one day's molding, is the direct molding labor cost, and the indirect costs are distributed entirely upon a percentage of the molding

direct labor. The core price or core cost, the piece work price, or in a day work shop, the cost of making the cores for one day's molding, and the core overhead in this system is distributed upon a percentage of the direct core making labor.

I would like to suggest, however, that the gray iron foundries that are interested in cost work make some investigations of their own upon the advisability of using the weight of core sand as a basis for distributing their indirect core costs.

Cleaning expense included either so much a pound for the day's work or so much a piece for the casting, or a percentage of the direct molding labor, and we have made provision for deductions for scrap and, incidentally, additions for profit.

I think that describes briefly the method of estimating; the system has been published in *The Foundry* magazine, and I submit it here for publication in these Transactions. If there are any questions that I can answer, I will be glad to do so.

H. S. WASHBURN⁴: Mr. Grede, how would you estimate the weight of an intricate core in quoting from a blueprint?

MR. GREDE: In answer to Mr. Washburn's question, I would say that in one of our plants where we make automotive cylinders, heads, manifolds and work of that kind. When we started estimating the weight of cores, it seemed like an impossible task, but we found that our estimators were soon able to estimate the weight of a core as accurately as they estimated the weight of a casting, and I think that the error in estimating core weights will not be any greater after some experience than estimating of castings.

I think it has done this for us in some cases; it has brought our attention to cores that the original estimator might have overlooked. So we have been able to add into our costs some direct core making labor that might have been overlooked if we had not been estimating core weights.

CHAIRMAN TOUR: It is certainly interesting to note a wider range of work in shape and size of gray iron castings than malleable iron castings, and a simultaneous attempt to get a simpler estimating system—which will disregard yields and cleaning costs on specific jobs.

In spite of the fact that the malleable industry has a narrower range they have to study yields and cleaning costs, even in their narrower range. In my opinion there is danger in going too far in simplification and ruining the entire objective of a cost estimating system. In my opinion estimated costs should be somewhere within gunshot of actual, and should make it possible to stay in business and make money and not swap dollars.

I was, therefore, very much pleased to hear Mr. Grede state that although in the simplified method cleaning costs are a part of the overhead on molding direct labor, it was not specified as the only method.

I appreciate it is always necessary to start out in a small way and to get the shop to use a simple method before starting a more complicated method. If the simple method is so simple that it does not answer the

⁴The Plainville Casting Company, Plainville, Conn.

purpose and the shop trying it loses money, then they become antagonistic to all systems and the battle is lost.

With these remarks as to the limitations and with the qualifying recommendations that this simplified gray iron system is only a start, and preferably should not be used in its very simplest form, I am heartily in favor of it.

MR. BELT: Mr. Chairman, there are one or two points to which Mr. Grede referred that might be explained further as applied to malleable iron and gray iron.

Certainly yield is not of the same importance in gray iron as it is in malleable iron. You do not have to feed a gray iron casting to nearly the same extent that you do a malleable iron casting to get a sound product. The average yield in many malleable iron plants runs as low as forty-five per cent. You pour on the average more than two tons of metal to get a ton of good castings, and, as I explained, some jobs run as low as thirty per cent, and others as high as seventy per cent. I am certain you will not find that range in gray iron.

Another point is with reference to distribution of cleaning costs. In certain gray iron shops certainly cleaning costs ought to be regarded as direct labor, because cleaning is an appreciable item and an expensive operation as compared with tumbling, which is prevalent practice in the malleable iron industry. So you cannot make a comparison of the methods of application of cleaning costs in the two branches of the industry because the cleaning operations are usually different.

Reference was also made to the application of a normal overhead. While I did not explain it in the paper I presented, we, of course, reckon with normal operations in the application of fixed charges,—fixed plant charges, and administrative and selling expense.

MR. RENTSCHLER: With regard to Mr. Belt's comments on cleaning, he talks about the variation in the gray iron industry of large castings with small castings. I think if any of these men are in the light gray iron casting business, they will find in many instances that their cleaning costs (at least, this is true in a lot of cases with us) are well in excess of our combined molding and core costs, and it does not of necessity have to be a large casting or a heavy casting.

The lighter castings will perhaps require hand sandblasting, individual handling by gauging, filing and finishing, or what not, that run your cleaning costs to much bigger proportions in the total cost than the actual molding.

While I have the floor, I would like to take some little exception to Chairman Tour's remarks concerning this simple system, that it might be a mistake to promulgate a system that might be too simple. Personally, I think we would all be better off if we would each have for ourselves a system that is more refined than the simple system, but if we had everybody in the gray iron industry following the principles outlined in the simple system, I think the whole industry would be on a far sounder basis than it is today, because the principles that are covered in the simple cost system Mr. Grede has outlined are merely refined. As you go into more elaborate costing and as each foundryman follows the simple system, he acquires a desire to elaborate more on his costs and follow

through on the various items that appear more excessive than he would normally expect. So that I am, personally, of the opinion that the simple system, if adopted by everybody in the gray iron industry, would readily put the industry on a much sounder basis.

CHAIRMAN TOUR: I want to agree with Mr. Rentschler on that, too, that certainly this system is better than basing a price on what somebody else has quoted.

MR. GREDE: I appreciate very much Mr. Rentschler and Mr. Belt coming to my defense on some of these criticisms, and when I speak about the wide variety in the gray iron industry, I speak, of course, about the industry as a whole, and if my remarks are interpreted as applying to any particular plant, they are apt to be misleading. I think you will find in the gray iron industry that there is a considerable degree of specialization. The light foundry makes mostly light work; therefore, has a comparatively uniform yield and can establish a simple method of calculating costs, including cleaning costs, that will pretty well apply to its production.

A heavy shop also has some degree of uniformity as to yield, and while it may select a different one of the recommended cleaning cost methods, it can determine the cleaning cost method that will give pretty good average results in the particular plant.

R. O. FLANDERS²: A point was raised in the discussion of the malleable cost system, which I think could well be brought out under the consideration of a cost system for gray iron foundries—namely, that the units of the malleable industry are larger on the whole than those in the gray iron industry. That is, that there are more small units operating as gray iron foundries than as malleable foundries, and that the large units could stand the trouble and expense of installing a cost system easier than the small units.

A question was asked as to the difficulty and expense encountered in installing such a system in malleable shops. To bring that point home to the gray iron foundry—and what I say here is addressed to those smaller units—I just want to relate some experiences that we have had along that line.

I represent a small unit. Some years ago we woke up to the fact that our accounting system, particularly our cost work, had, like Topsy, "just growed," and was sadly in need of revision. With that idea in mind we set to work to find out what we could about approved gray iron cost accounting methods and came in contact with the GRAY IRON INSTITUTE of that day, with their simplified cost method that they had published.

After careful investigation of this and other systems, and going into the problem of the trouble and cost of installing such systems in our plant, we started to work to install the GRAY IRON INSTITUTE system. The installation required around six or eight months' time. We did not throw all we had out the window, however, and start from the bottom up. We took the system a piece at a time, starting with the general accounting system first, in order to build up the classification of accounts

² Blue Valley Foundry Company, Kansas City, Mo.

needed to secure the operating experience and statistical data on which an operating cost system is based. Without going into details, we now have what we feel is a cost accounting system ample for our needs. The cost of installation was certainly not excessive, and while there was some confusion at first, I can say that it has been a rejuvenation for our entire business. Instead of operating on a basis of trading dollars and sometimes being in doubt of that, we have placed our business on a profitable basis, and the system has proved well worth all the trouble and expense it caused. In fact, we would not consider going back to our former method.

CHAIRMAN TOUR: That is very interesting indeed. There being no more discussion on the gray iron cost system we will proceed to the next discussion on the program, "Non-Ferrous Foundry Cost Methods," by J. L. Wick of the Falcon Bronze Co., President of the A.F.A.

... Mr. Wick presented his paper (see pages 727 to 740.)

CHAIRMAN TOUR: This non-ferrous system was actually tried out in small foundries. If the foundry has a check book, a record of pay roll and figures on what the fellows did for a few months and a bookkeeper or somebody who wants to figure, it is possible to set up the figures of departmental overhead, the figures as to burden for each job, and set up the basic figures which lead to the formula for estimating costs in not over two days. It isn't a ten year job or a six months' job. In two days it can be done in a small foundry.

As the foundries become larger, it takes more time, of course, but the objection has always been that a small foundry can't put in a cost system. It has been proved, however, that in two days any small foundry can be intelligently estimating costs, and estimating prices based upon actual cost of production and not upon what somebody else quoted.

C. I. RITCHIE: Mr. Wick said in one of his statements that he calls in the American Appraisal Company and they appraised all of his equipment. I would like to know, just as a point of information, what is the difference between appraisal and normalizing. Understand, I am not standing up for the N.R.A. in that, but I would just like to know for my own information.

MR. WICK: I don't know what normalizing is. We have an investment there. We are carrying insurance on it. We are paying taxes on it. We have it on our books, so much for equipment, so much for buildings. Now let's distribute that by departments in which that equipment is used. Why should we charge the floor molding with the overhead on a lot of equipment that may be out in the cleaning department? That should go against cleaning. The same with the cores. Why should the molding department carry any core expense? If you are going to put your core cost on everything that goes through the foundry, what are you doing? You are getting a lot of intricate high cost core castings at a price that is too low and you are driving away all flat simple work because you have some core work in it.

We called in the American Appraisal Company for our reproductive values. There are dozens of good appraisal companies.

* Gray Iron Founder's Society, Cleveland, O.

CHAIRMAN TOUR: I might try to clarify this. This question of normalizing and this question of appraisal values, etc., is common to all foundries. It is not peculiar to the non-ferrous foundry. They are separate and distinct items. There is no relation between this question of normalizing and the question of whether you have an appraisal or not.

Normalizing has to do with plant capacity versus actual rate of operation. Is the true cost the cost of producing a small quantity in a large plant or is it the cost of producing when the plant is operating at a normal rate?

In other words, are costs to be fluctuating up and down as one order is obtained or one order lost?

Normalizing is an attempt to standardize at a given volume of business. If you fall below that volume of business, you are below normal and even though the price is maintained the same, you lost money; and if you do more business than that normal, you will make more money. At normal you get the estimated profits of your estimates.

For example, with a plant capacity of \$100,000 annual business, \$60,000 would be considered the normal volume at which a profit should be made. Doing less business means a loss. Doing more business means higher profits. Cost estimates remain the same.

In order to determine depreciation, interests on investments, etc., you have to know what the investment is. Maybe the investment is based upon obsolete or obsolescent equipment, so you have to set a value upon equipment today and determine what is its proper value, and that is the question of appraisal.

It so happens that there are many old foundries in the country, small shops that are operated by one man or a man and his family. There may be a half dozen men in the shop who by some manner or other got hold of a plant and have been running it for a number of years. They may have paid off the mortgage, etc. They do not figure any interest on investment. They do not figure any depreciation. They estimate costs lower than somebody who proposes to maintain a good, up-to-date foundry. They have no surplus to use for new equipment.

During N.R.A. days an attempt was made to prevent the complete wiping out of all items of cost that have to do with interest on investment, depreciation, amortization, etc., and that is where appraisal comes in. Whether you call in the American Appraisal Company or whether you go back and check up your records as to what you paid for equipment and size up the equipment and say, "Well, it is worth 50 per cent today of what I paid for it a year ago"—or maybe 200 per cent—it doesn't make any difference providing it is a fair appraisal. Having made that appraisal, then you should certainly figure as an item of cost interest on that investment, depreciation and amortization of that investment.

MR. WICK: Even though your plant and equipment has been completely depreciated, you should include in your cost depreciation based on the cost of replacement or reproduction.

CHAIRMAN TOUR: Sometimes people figure that equipment has been wiped off the books because the Treasury Department in Washington says "You have depreciated it 100 per cent and therefore you can't figure it as inventory or anything else." Actually one must figure those things in

cost. If they are old they are often inefficient. Modern equipment must be installed some day.

I want to correct one other thing Mr. Wick said. That is, in the system as drawn up the distribution of fixed overhead was based upon either floor space in each department or appraisal of equipment installed in each department, preferably, and only as an optional method was it distributed on the basis of labor thus acknowledging that the basis of labor was not correct.

WITOLD W. KOSICKI: I want to speak about that little fellow. The big plant has an estimator and a timekeeper, but the little fellow has only two or three molders. He will have a job come in and he will determine what it will cost. What is next? Tell me how in future he can determine his price?

CHAIRMAN TOUR: That is a question I can't very well undertake to answer here, but the answer is in the system as presented by Mr. Wick. All you have to do is to use it. If a small foundry gets a formula for figuring costs and does not use the formula, nothing can be done about it. All that small man has to do is to intelligently figure how long it is going to take to mold this job, how long it is going to take to make cores for the job, how long it is going to take to clean the job, how much metal is going to be in the finished job, how much he is going to lose in the way of bad castings, what his shrinkage is going to be. That is just intelligent foundry practice. If he does know that it is simple enough to figure his costs.

MR. BELT: There is one other point I would like to clear up if it needs any clarification. Mr. Grede referred to the malleable procedure as using a weight basis for the distribution of the molding department indirect expense. I think he has in mind the weight of good production. We do not use the weight of good production as a basis for distribution of any part of the molding department indirect expense. We use the weight of metal poured because we have found that the indirect expense of the molding department bears a far closer relation to the weight of metal poured than to the weight of good production.

For example, it costs just as much to handle scrap and sprue as it does to handle good castings, and it takes just as much sand to mold scrap, sprue and heads as it does to mold good production, so we use the weight of metal poured as a basis in preference to the weight of good production.

⁷ Metalloy Products Co., Detroit, Mich.

An Improved Method for Preparing Cast-Iron Transverse Test Bars*†

By A. I. KRYNITSKY AND C. M. SAEGER, JR.,‡
WASHINGTON, D. C.

Abstract

The importance of preparing cast-iron transverse-strength test bars free from "burnt-on" sand and surface defects is discussed. A molding material and casting technique which will produce such test bars in green-sand molds has been developed. Test bars 0.75, 1.2, 1.5, and 2.2 inches in diameter and 23 inches in length were cast in top-poured and bottom-poured vertical molds, horizontal molds, and horizontally inclined molds. The effect of maximum heating temperature on the transverse breaking strength, hardness, primary structure, and microstructure of test bars made by these methods was investigated. Test bars cast in bottom-poured vertical molds yielded the most consistent results. The transverse breaking strength of the irons investigated increased with an increase of the maximum heating temperature, regardless of the casting method employed. A finer primary structure and finer graphite and pearlite constituents were found to be associated with higher transverse strength.

INTRODUCTION

1. In an investigation of the effect of maximum heating temperatures on the physical properties of different types of cast irons,¹ a method was developed at the National Bureau of Standards for making transverse-strength test bars in dry-sand molds. The Committees on Cast Iron of both the American Society for

* Full paper was published in the April, 1936, issue of the Journal of Research of the National Bureau of Standards (Research Paper RP 880).

† Publication approved by the Director of the National Bureau of Standards of the U. S. Department of Commerce.

‡ Associate Metallurgist and Metallurgist, respectively, U. S. Bureau of Standards.

¹ Superior figures throughout the text indicate references given in the references at the end of this paper.

Testing Materials and the AMERICAN FOUNDRYMEN'S ASSOCIATION have expressed their interest in this subject and pointed out the desirability of extending the investigation to include a study of transverse-strength test bars made in green-sand molds.

2. It is well known that bars used for the determination of transverse strength should not only be free from "burnt-on" sand but should also have a smooth surface, since the breaking strength of a test piece may be seriously affected by the character of its surface. The removal of burnt-on sand by sand blasting or tumbling may leave the surface pitted or roughened, which condition may cause the bars to break under a relatively low load by the so-called "notch effect".

3. Many investigators are of the opinion that the surface layer on test bars should be removed by machining before the bars are tested. This point was strongly emphasized in the discussion of the paper entitled "Relationship in Cast Iron Test Results."² It is believed by many investigators that the surface layer or so-called "surface skin" is the strongest part of the bar and, therefore, one should expect its removal to lower the transverse strength. It has been found¹ experimentally that the removal of the surface layer lowers the strength under transverse loading, although the results of some other investigators are not in agreement with this. However, surface defects, such as those mentioned earlier, might account for these results, which indicate the transverse strength of a bar with the surface skin removed to be stronger than a similar bar without the skin removed.

4. In this investigation an attempt was made to prepare test bars in green-sand molds having smooth surfaces free from burnt-on sand. Factors such as the horizontal or vertical position of the mold, the location and size of the gates and risers, the molding and facing materials, the permeability, strength and degree of ramming of the mold, and the temperature of the metal and rate at which it is poured into the molds, are important and should be considered in producing satisfactory test bars.

5. The investigation is naturally divided into two parts, the first, to develop a molding procedure which will yield satisfactory test bars when green-sand molds are used, and the second, to compare the results obtained on test bars produced by pouring (1) by the method developed at this Bureau and (2) by the three tentative methods specified by the American Society for Testing Materials.³

MOLDING AND CASTING TECHNIQUE

6. A molding material to be suitable for this purpose must be such that it is possible to make satisfactory bars of various diameters with irons of various chemical compositions. It was felt that the molding material would be satisfactory if it yielded satisfactory test bars free from burnt-on sand and surface defects, when the following types of irons, and the following melting and casting procedure is used to produce bars of the following sizes.

Types of Test Bars

7. The test bars prepared and studied in this investigation were 23 inches in length and 0.75, 1.2, and 2.2 inches in diameter, respectively. Similar bars, 1.5 inches in diameter, were also used to a limited extent.

Test-Bar Molds

8. The bottom-poured vertical mold, which was developed for casting test bars in dry sand,¹ was used in this phase of the investigation. In this method a set of cylindrical test bars, consisting of four pairs molded in a three-part cylindrical flask, with the cheek extending the full length of the bar, were made in green sand (Fig. 1). The diameters of the various bars were 0.75, 1.2, 1.5, and 2.2 inches, respectively. The bars were arranged so as to minimize the heating effect of the large bars on the small ones during cooling after casting.

Stock Iron

Table 1

RESULTS OF CHEMICAL ANALYSES OF STOCK IRONS USED

Iron	Total Carbon %	Silicon %	Manga- nese %	Phos- phorus %	Sulphur %	Copper %	Nickel %	Chro- mium %
A	3.99	1.70	0.70	0.59	0.045	0.51	...	...
B	3.41	1.63	0.49	0.44	0.073	...	0.10	0.13
C	3.79	1.32	0.73	0.12	0.06	...	...	...
D	2.86	2.06	0.18	0.65	0.028	...	...	...
E	3.55	2.73	0.24	0.82	0.021	...	...	...
F*	2.13	1.64	0.14	0.49	0.013	...	...	...

* Chemical analysis calculated.

9. The types of irons used are shown in Table 1. Irons A, C, and E were sand-cast pig irons. Iron B was a specially selected scrap iron; D, a mixture of E and 20 per cent of commercial open-

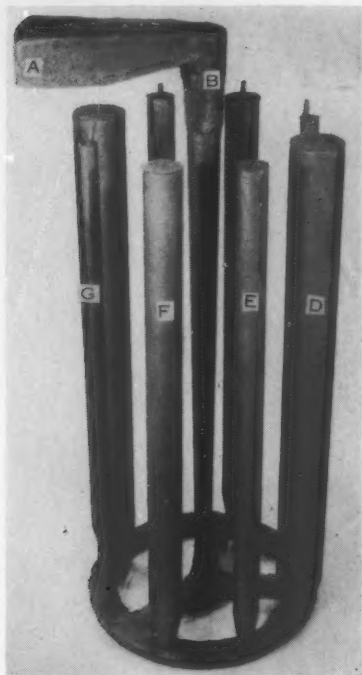


FIG. 1—CASTING SHOWING THE METHOD OF POURING BARS FOR TRANSVERSE TESTS. A, POURING BASIN; B, DOWN GATE; C, FEEDING RING; D, 2.2-INCH BAR; E, 1.2-INCH BAR; F, 1.5-INCH BAR; G, 0.75-INCH DIAMETER BAR.

hearth ingot iron; and F, a mixture of E and 40 per cent of commercial open-hearth ingot iron.

Melting and Casting Procedure

10. The irons were melted in a crucible of commercial magnesia in a high-frequency induction furnace of the tilting type. Charges of 200 pounds of metal were heated to maximum heating temperatures of 1,400° C (2,550° F); 1,500° C (2,730° F); 1,600° C (2,910° F); and 1,700° C (3,090° F), respectively, and held at the maximum heating temperature for approximately 1 minute before being allowed to cool to the desired pouring temperature.

11. The metal was allowed to cool from the maximum heating temperature to approximately 150° C (270° F) above the liquidus temperature of the stock pig iron or mixture used in that particu-

lar charge. It was then poured directly from the furnace into the test-bar molds, and the bars allowed to remain in the mold for a period of not less than 18 hours. The liquidus temperature was obtained from the diagram in Fig. 2, which shows the relation⁴ between the liquidus temperature of cast iron and the total impurities.

Temperature Measurement of Molten Iron

12. Temperatures up to $1,550^{\circ}\text{C}$ ($2,820^{\circ}\text{F}$) were measured by a platinum-to-platinum 10 per cent rhodium thermocouple. The thermocouple wires were separated by means of a two-hole porcelain insulator and protected by a closed-end, glazed, porcelain tube inserted into a closed-end graphite tube. The portion of the

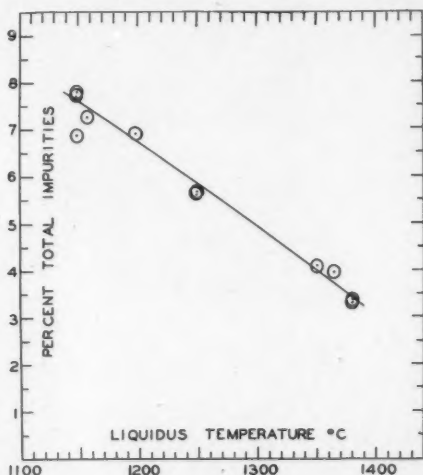


FIG. 2—RELATION OF LIQUIDUS TEMPERATURE TO TOTAL IMPURITIES IN CAST IRON.

graphite tube, which came in contact with the molten iron, was coated with a layer of aluminum oxide over which a layer of a mixture of 95 per cent of zircon (zirconium silicate) and 5 per cent of bentonite was applied. The thermocouple assembly is shown in Fig. 3. An optical pyrometer was used for measuring temperatures above $1,550^{\circ}\text{C}$ ($2,820^{\circ}\text{F}$). In order to determine the corrections to be applied to the readings of the optical pyrometer under these particular conditions, observations were taken simultaneously with both the thermocouple and the optical pyrometer

in the temperature range 1,400 to 1,550° C (2,550 to 2,820° F). These corrections were then plotted as a function of the temperature, and the curve extended up to 1,700° C (3,090° F).

Molding Material

13. Considerable preliminary work was necessary with green-sand molds to develop a suitable molding material which would yield test bars free from surface defects or "burnt-on" sand. A number of bars were cast in green-sand molds of various moisture contents made from an iron molding sand commercially known as

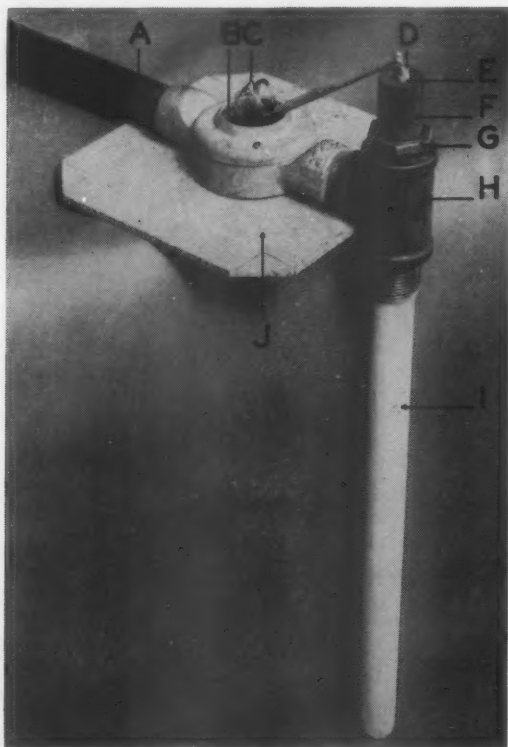


FIG. 3—THERMOCOUPLE ASSEMBLY USED IN MEASURING TEMPERATURES OF MOLTEN CAST IRON. A, THERMOCOUPLE-HANDLE ENCLOSING EXTENSION LEADS; B, THERMOCOUPLE JUNCTION WITH EXTENSION LEADS; C, PLATINUM-PLATINUM RHODIUM THERMOCOUPLE WIRES; D, 2-HOLE PORCELAIN INSULATING TUBE; E, PORCELAIN TUBE; F, GRAPHITE TUBE; G, SPLIT LOCK NUT; H, PIPE TEE; I, REFRACTORY COATING APPLIED TO GRAPHITE TUBE; J, HEAT INSULATING PLATE.

Lumberton molding sand (AMERICAN FOUNDRYMEN'S ASSOCIATION grade 3-C). An excessive amount of burnt-on sand in each case was noted.

14. Further tests were made with molds of the same molding material in which the cavities were coated with a facing material such as ceylon graphite, as well as a nongraphitic carbonaceous material.* Mixtures of the nongraphitic carbonaceous material with bentonite, silica flour, aluminum-oxide cement, or portland cement were also tried as facing material. These were applied by dusting, by brushing with a camel hair brush, and by swabbing with a hemp swab. In each case the facing material was applied in dry form. None of the bars made in molds so treated was satisfactory on account of burnt-on sand.

15. Mixtures of sand and sea-coal were tried with some degree of success. A mixture of 8 parts of molding sand to 1 part of sea-coal, tempered to approximately 7 per cent of moisture, was used in making molds. However, the test bars made in these molds were not entirely satisfactory because of the roughened surface and, to some extent, burnt-on sand. By facing the mold cavities with a fine ceylon graphite, bars were obtained that were free from burnt-on sand, although the surfaces of the bars were still very rough. However, by swabbing the mold surfaces with a nongraphitic carbonaceous material, bars which were free from burnt-on sand and which possessed a very smooth surface were obtained.

16. This molding mixture composed of 8 parts of molding sand to 1 part of sea-coal, tempered to approximately 7 per cent of moisture, with the mold cavities faced with a nongraphitic carbonaceous facing material, was used in the remainder of the experiments and will be referred to as the "selected molding material."

17. Two experiments were conducted to determine the temperature of the sand between different sizes of test bars immediately after casting. The purpose of these experiments was to determine if the molding sand reached a temperature high enough to produce appreciable annealing effects in the bars. This is particularly of interest in those cases where a small diameter bar is cast in the same mold with larger bars. In both experiments a casting similar to that shown in Fig. 1 was made. In the first

* Approximate analysis:

Volatile matter	4.0%
Fixed carbon	74.0%
Ash	22.0%

mold, two thermocouples were inserted, one midway between the 0.75- and 2.2-inch bars, and another, between the 0.75 and 1.50-inch bars. The metal was poured into the mold at $1,400^{\circ}\text{C}$ ($2,550^{\circ}\text{F}$), and the temperatures at these two points were recorded as the mold cooled to room temperature. At the end of 50 minutes the temperature between the 0.75, and 2.2-inch bars was 300°C (570°F), the maximum observed, while the maximum temperature observed between the 0.75- and 1.5-inch bars was 170°C (340°F). The metal was poured into the second mold at $1,380^{\circ}\text{C}$ ($2,515^{\circ}\text{F}$) a thermocouple being placed midway between the 1.5- and 0.75-inch bars and one between the 1.2- and 2.2-inch bars. The maximum temperature observed between the 1.5- and the 0.75-inch bars was 165°C (330°F) and between the 1.2- and the 2.2-inch bars, 400°C (750°F), at the end of 40 minutes.

18. On the basis of these results, it is doubtful whether the molding material reached a temperature sufficiently high to have a marked influence on the physical properties of the test bars.

Uniformity in Dimensions of Test Bars

19. Measurements were made to determine the variation in diameter of the bars of different sizes using the selected molding material described earlier. The diameter of each bar was measured at the midsection in four radial directions. The difference between the maximum and minimum diameters is expressed (Table 2) in percentage of the average diameter. The 2.2-, 1.2-, and 0.75-inch bars were tested under transverse loading in an Amsler universal testing machine of 50,000-pound capacity, the load being applied to give approximately 0.02-inch deflection in 10 seconds. The span used for the 1.2- and 2.2-inch bars was 18 inches, and for the 0.75-inch bars, 15 inches. The breaking load for each bar was calculated to the nominal diameter and the difference between the breaking loads of the two bars of the same size was calculated as the percentage of the highest breaking load for the pair (Table 2). It will be noted from Table 2 that the maximum variation in all the bars tested was 0.77 per cent in the diameter and 6.2 per cent in the breaking load. Complete data on the results of the transverse tests of these bars will be considered later in this paper.

Four Methods of Preparing Test Bars

20. In the second phase of this investigation, a comparison was made of the physical properties of transverse-strength test bars made by the method developed at this Bureau and by the

methods tentatively adopted by the American Society for Testing Materials. These methods differ only in the position in which the bar is cast and the method of pouring. In the method developed at this Bureau, the bars are cast in a vertical position and poured from the bottom. Bars produced in this manner are referred to as bottom-poured vertical mold. The American Society for Testing Materials has tentatively adopted three methods of casting transverse-strength test bars. In one method, the bars are cast in a vertical position and poured from the top (top-poured vertical mold). In another, the bars are cast in a horizontal position (horizontal mold) and in the third, they are cast in a position inclined about 8 degrees with the horizontal (horizontally inclined mold). In the latter case, the bars are poured from the lower end. Test bars 0.75, 1.2, and 2.2 inches in diameter were produced by

Table 2

VARIATIONS IN DIAMETERS¹ OF CYLINDRICAL TEST BARS CAST IN BOTTOM-POURED VERTICAL GREEN-SAND MOLDS AND IN TRANSVERSE BREAKING STRENGTH OF COMPANION BARS

IRON A

Temperature				Average diameter	Difference between maximum and minimum diameter	Difference in breaking load
Maximum heating		Pouring				
°C	°F	°C	°F	Inches	Percent	Percent
1,400	2,550	1,300	2,370	2.26	0.18	3.8
1,400	2,550	1,300	2,370	2.24	.36	
1,400	2,550	1,300	2,370	1.55	.45	(1)
1,400	2,550	1,300	2,370	1.55	.32	
1,400	2,550	1,300	2,370	1.24	.50	2.2
1,400	2,550	1,300	2,370	1.24	.31	
1,400	2,550	1,300	2,370	.79	.63	1.4
1,400	2,550	1,300	2,370	.79	.39	

IRON B

1,400	2,550	1,380	2,515	2.24	0.13	0.6
1,400	2,550	1,380	2,515	2.24	.18	
1,400	2,550	1,380	2,515	1.54	.32	(1)
1,400	2,550	1,380	2,515	1.55	.18	
1,400	2,550	1,380	2,515	1.24	.32	.4
1,400	2,550	1,380	2,515	1.24	.33	
1,400	2,550	1,380	2,515	.80	.37	2.2
1,400	2,550	1,380	2,515	.80	.41	
1,600	2,910	1,380	2,515	2.23	.23	.9
1,600	2,910	1,380	2,515	2.23	.27	
1,600	2,910	1,380	2,515	1.54	.40	(1)
1,600	2,910	1,380	2,515	1.54	.39	
1,600	2,910	1,380	2,515	1.23	.40	4.4
1,600	2,910	1,380	2,515	1.23	.32	

¹ Bars cast for machining to 1.2-in. diameter, not tested for transverse strength.

Table 2—Continued
IRON C

Temperature				Average diameter	Difference between maximum and minimum diameter	Difference in breaking load
Maximum heating		Pouring				
°C	°F	°C	°F	Inches	Percent	Percent
1,400	2,550	1,300	2,370	2.24	0.40	3.2
1,400	2,550	1,300	2,370	2.25	.40	
1,400	2,550	1,300	2,370	1.54	.70	(1)
1,400	2,550	1,300	2,370	1.54	.26	
1,400	2,550	1,300	2,370	.78	.77	3.2
1,400	2,550	1,300	2,370	.78	.63	
1,500	2,730	1,380	2,515	2.25	.40	3.5
1,500	2,730	1,380	2,515	2.25	.35	
1,500	2,730	1,380	2,515	1.55	.45	(1)
1,500	2,730	1,380	2,515	1.54	.71	
1,500	2,730	1,380	2,515	1.23	.50	2.3
1,500	2,730	1,380	2,515	1.23	.32	
1,500	2,730	1,380	2,515	.80	.38	6.2
1,500	2,730	1,380	2,515	.80	.50	
1,600	2,910	1,380	2,515	2.24	.27	4.2
1,600	2,910	1,380	2,515	2.24	.27	
1,600	2,910	1,380	2,515	1.54	.19	(1)
1,600	2,910	1,380	2,515	1.54	.32	
1,600	2,910	1,380	2,515	1.23	.33	3.1
1,600	2,910	1,380	2,515	1.23	.24	
1,600	2,910	1,380	2,515	.79	.51	.5
1,600	2,910	1,380	2,515	.78	.57	
1,700	3,090	1,380	2,515	2.24	.50	.3
1,700	3,090	1,380	2,515	2.25	.31	
1,700	3,090	1,380	2,515	1.55	.32	(1)
1,700	3,090	1,380	2,515	1.55	.38	
1,700	3,090	1,380	2,515	1.23	.48	3.2
1,700	3,090	1,380	2,515	1.23	.40	

¹ Bars cast for machining to 1.2-in. diameter, not tested for transverse strength.

each of the above-mentioned methods. In view of the satisfactory results obtained in the earlier work with the mixture of 8 parts of molding sand to 1 part of sea-coal, tempered to approximately 7 per cent of moisture and faced with a nongraphitic carbonaceous refractory material, these materials were used to make the molds for casting transverse-strength test bars by each of four methods.

21. (a) *Top- and Bottom-Poured Vertical Mold*: The mold used, in making these bars shown in Fig. 4, was a modification of the one used for making the bars shown in Fig. 1. Bars of the same diameter were cast in pairs simultaneously in a vertical mold, 2 bars being bottom-poured, and 2 bars being top-poured. The molds were made in a three-part cylindrical flask, with the cheek extending the full length of the bars, and the mold cavities were spaced 7 inches between centers.

22. (b) *Horizontal Mold*: Two bars of the same diameter were cast simultaneously through filter cores, with the ends of the bars provided with risers (Fig. 5). The distance between the

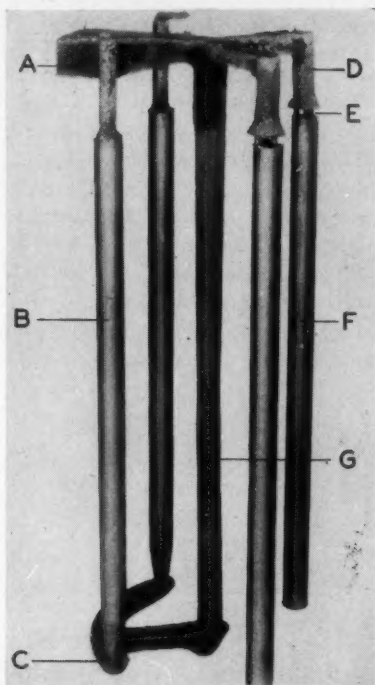


FIG. 4—TRANSVERSE-STRENGTH TEST BARS CAST IN A VERTICAL MOLD BY TOP-POURING AND BOTTOM-POURING. A, POURING BASIN; B, VERTICALLY CAST BARS, BOTTOM-POURED; C, FEEDING SEMI-RING FOR BOTTOM-POURING; D, TOP-POURING GATES; E, PENCIL GATES OF 0.25-INCH DIAMETER MADE IN OIL-SAND CORES; F, 5 PENCIL GATES FOR 2.2-INCH DIAMETER BARS; 3 PENCIL GATES FOR 1.2-INCH DIAMETER BARS; 1 PENCIL GATE FOR 0.75-INCH DIAMETER BARS; G, DOWN GATE.

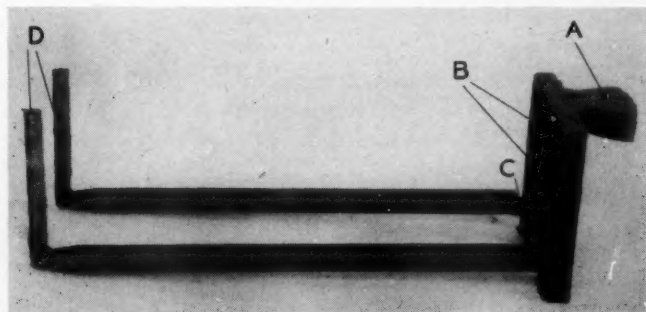


FIG. 5—TRANSVERSE TEST BARS CAST HORIZONTALLY. A, POURING GATE; B, DOWN GATES $1 \times 2.25 \times 10$ INCHES; C, PENCIL GATES OF 0.25-INCH DIAMETER, 5 GATES FOR 2.2-INCH DIAMETER BARS, 3 GATES FOR 1.2-INCH BARS, 1 GATE FOR 0.75-INCH DIAMETER BARS; D, RISERS.

center line of the 2 bars was 6 inches. The patterns used in making these bars were removed by withdrawing them from one end of the flask, thereby eliminating parting-line defects in the mold cavities such as may be encountered when the cope is removed from the drag and the pattern is lifted out from the mold.

23. (c) *Horizontally Inclined Mold*: The mold used in making the bars shown in Fig. 6 was similar to the horizontal mold, with the exception that the risers were connected to an overflow basin, which served as a reservoir to retain the excess of metal poured through the test bar mold during casting. The mold was inclined at an angle of 8 degrees while it was being poured.

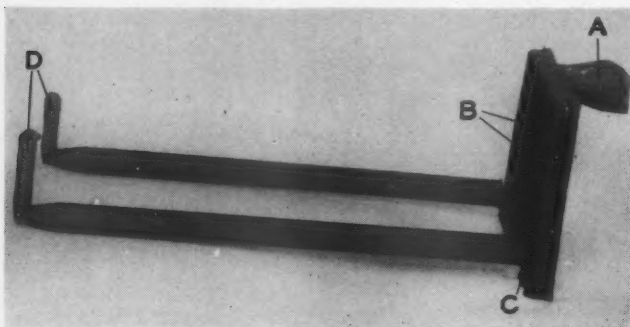


FIG. 6—TRANSVERSE TEST BARS CAST IN A HORIZONTALLY INCLINED MOLD. A, POURING GATE; B, DOWN GATE 1×2.25×10 INCHES; C, FEEDING GATE; GATES OF 1-INCH DIAMETER FOR 2.2-INCH DIAMETER BARS, GATES OF 0.75-INCH DIAMETER FOR 1.2-INCH DIAMETER BARS, GATES OF 0.5-INCH DIAMETER FOR 0.75-INCH DIAMETER BARS; D, RISERS TO OVERFLOW BASIN.

Surface Condition and Dimensional Uniformity of Test Bars

24. The surfaces of all bars were smooth and free from burnt-on sand, this being true even when a pouring temperature of 1,470° C (2,680° F) was employed. The diameter of each test bar was measured at midsection of the bar in four radial directions, and the differences between the maximum and minimum diameters expressed as the percentage of the average diameter. The results (summarized in Table 3) on 64 bars cast by the four methods show that the vertically cast bars, particularly those which were bottom-poured, were much more uniform in their diameter than the bars cast in the horizontal or the horizontally inclined molds.

Table 3
VARIATIONS IN DIAMETER¹ OF TEST BARS CAST BY FOUR METHODS.

Iron	Temperature				Vertical mold				Horizontally inclined mold		Horizontal mold	
	Maximum heating		Pouring		Top poured		Bottom poured		Average	Maximum variation	Average diameter	Maximum variation
					Average diameter	Maximum variation	Average diameter	Maximum variation				
	°C	°F	°C	°F	in.	%	in.	%	in.	%	in.	%
A-----	1,500	2,730	1,300	2,370	1.25	0.04	1.24	0.48	1.24	2.02	1.25	2.16
	1,500	2,730	1,300	2,370	1.25	.48	1.24	.24	1.24	1.21	1.25	2.00
A-----	1,600	2,910	1,300	2,370	.80	.62	.80	.60	.82	7.60	.80	2.12
	1,600	2,910	1,300	2,370	.80	1.62	.80	.75	.81	4.67	.80	1.12
A-----	1,600	2,910	1,300	2,370	1.25	.48	1.24	.08	1.24	.81	1.24	.81
	1,600	2,910	1,300	2,370	1.25	.32	1.24	.40	1.24	.73	1.25	1.86
A-----	1,600	2,910	1,300	2,370	2.25	.27	2.24	.31	2.26	1.37	2.27	1.10
	1,600	2,910	1,300	2,370	2.25	.62	2.25	.44	2.25	1.51	2.27	1.23
A-----	1,700	3,090	1,300	2,370	1.25	.88	1.24	.56	1.25	2.72	1.26	1.50
	1,700	3,090	1,300	2,370	1.25	.64	1.24	.32	1.25	1.60	1.25	1.36
C-----	1,400	2,550	1,380	2,515	1.26	.08	1.24	.32	1.25	2.16	1.26	2.14
	1,400	2,550	1,380	2,515	1.26	.71	1.24	.80	1.25	.64	1.26	2.03
D-----	1,700	3,090	1,380	2,515	1.25	.64	1.24	.56	1.25	2.24	1.25	1.84
	1,700	3,090	1,380	2,515	1.25	.56	1.24	.56	1.25	1.52	1.25	2.32
F-----	1,700	3,090	1,470	2,680	1.23	.57	1.22	.08	1.23	.89	1.23	.73
	1,700	3,090	1,470	2,680	1.23	.24	1.22	.24	1.23	.65	1.23	.83

¹ Diameters measured at midsection of test bars, in four radial directions.

Physical Properties of Test Bars

25. (a) *Transverse Breaking Test*: The results of the transverse breaking tests are shown in Tables 4 and 5, and the chemical analyses of the different bars in Table 6. The results determined on bars cast as shown in Fig. 1 in the bottom-poured vertical mold are also included. In view of the fact that higher breaking strengths have been reported for transverse-strength test bars cast in horizontal position when tested with the "cope side" up,^{5,6} the test bars cast in the horizontal and the horizontally inclined molds were placed on the testing machine so that their position corresponded to their position in the mold.

26. It is noteworthy that the difference in breaking loads for the two bars of a pair is, in general, smaller for bars cast either horizontally or in bottom-poured vertical molds than for the bars cast in the horizontally inclined mold or in the top-poured vertical mold.

27. In comparing the effect of maximum heating temperature on the strength of the 1.2-inch bars made by different methods it

Table 4
PHYSICAL PROPERTIES OF TEST BARS CAST IN BOTTOM-POURED VERTICAL MOLDS*

Diam- eter	Maximum heating temperature		IRON A.—POURING TEM- PERATURE 1,300° C (2,370° F)				IRON B.—POURING TEM- PERATURE 1,380° C (2,515° F)				IRON C.—POURING TEM- PERATURE 1,380° C (2,515° F)				IRON D.—POURING TEM- PERATURE 1,380° C (2,515° F)			
	in	° F	Modu- lus of fer- rur- ture, avg	Dif- fer- ence	Break- ing load	Brin- nell num- ber, avg	Modu- lus of fer- rur- ture, avg	Dif- fer- ence	Break- ing load	Brin- nell num- ber, avg	Modu- lus of fer- rur- ture, avg	Dif- fer- ence	Break- ing load	Brin- nell num- ber, avg	Modu- lus of fer- rur- ture, avg	Dif- fer- ence	Break- ing load	Brin- nell num- ber, avg
2.2	1.400	2,550	3.8	3.8	8,487	136	37,200	0.16	13,826	210	48,000	0.25	10,037	173	44,000	0.20	10,373	173
2.2	1.400	2,550	2.2	2.2	8,607	186	42,700	.24	2,312	210	48,000	0.25	10,373	173	44,000	0.20	10,373	173
1.2	1.400	2,550	1.4	1.4	1,596	608	53,000	.23	2,321	210	48,000	0.25	2,103	173	44,000	0.20	2,103	173
.75	1.400	2,550	1.4	1.4	608	699	53,000	.23	701	210	48,000	0.25	594	173	44,000	0.20	594	173
2.2	1.500	2,730	4.7	4.7	1,527	153	47,200	.12	717	210	48,000	0.25	10,654	173	44,000	0.20	10,654	173
2.2	1.500	2,730	4.7	4.7	1,527	153	47,200	.12	717	210	48,000	0.25	10,654	173	44,000	0.20	10,654	173
1.2	1.500	2,730	4.7	4.7	1,741	153	47,200	.12	717	210	48,000	0.25	10,654	173	44,000	0.20	10,654	173
.75	1.500	2,730	4.7	4.7	1,741	153	47,200	.12	717	210	48,000	0.25	10,654	173	44,000	0.20	10,654	173
2.2	1.600	2,910	6.0	6.0	10,985	14	48,800	.14	18,226	214	53,300	.27	10,700	190	53,300	.23	10,700	190
2.2	1.600	2,910	1.8	1.8	11,682	14	51,000	.21	15,082	214	53,300	.27	11,174	190	53,300	.23	11,174	190
1.2	1.600	2,910	1.8	1.8	1,931	189	51,000	.21	2,721	214	53,300	.27	2,117	190	53,300	.23	2,117	190
.75	1.600	2,910	1.8	1.8	1,931	189	51,000	.21	2,721	214	53,300	.27	2,117	190	53,300	.23	2,117	190
2.2	1.600	2,910	4.1	4.1	1,863	19	54,300	.19	765	214	53,300	.27	890	190	53,300	.23	890	190
2.2	1.700	3,090	5.2	5.2	1,975	201	53,800	.18	12,027	214	53,300	.27	12,056	214	53,300	.23	12,056	214
2.2	1.700	3,090	5.2	5.2	2,063	201	53,800	.18	12,056	214	53,300	.27	12,056	214	53,300	.23	12,056	214
1.2	1.700	3,090	5.2	5.2	1,975	201	53,800	.18	2,264	214	53,300	.27	2,264	214	53,300	.23	2,264	214
.75	1.700	3,090	5.2	5.2	2,063	201	53,800	.18	2,264	214	53,300	.27	2,264	214	53,300	.23	2,264	214

* Brinell-hardness values determined with 3,000-kg load, using 10-mm ball.

Table 5
PHYSICAL PROPERTIES OF TEST BARS CAST BY DIFFERENT METHODS*

Diameter	Temperature		Horizontal mold			Horizontally inclined mold			Vertical mold, top-poured			Vertical mold, bottom-poured					
	Maximum heating	Pouring	Break-ing load	Dif-fer-ence	Modu-lus of rup-ture avg.	Bril-nell num-ber avg.	Break-ing load	Dif-fer-ence	Modu-lus of rup-ture avg.	De-flec-tion	Bril-nell num-ber avg.	Break-ing load	Dif-fer-ence	Modu-lus of rup-ture avg.	De-flec-tion	Bril-nell num-ber avg.	
1.2	1,500	2,720	1,300	2,370	1,619	0.15	176	1,949	0.5	51,700	0.21	182	1,850	4.7	47,200	0.17	183
1.2	1,500	2,720	1,300	2,370	1,646	0.15	176	1,908	0.5	51,700	0.21	182	1,522	4.7	47,200	0.17	183
2.2	1,600	2,910	1,300	2,370	10,738	0.15	176	11,070	2.9	48,400	0.15	182	11,400	6.0	48,500	0.14	183
2.2	1,600	2,910	1,300	2,370	11,463	0.15	176	11,500	2.9	48,400	0.15	182	10,985	6.0	48,500	0.14	183
1.2	1,600	2,910	1,300	2,370	1,831	0.22	178	1,894	3.7	51,100	0.22	178	1,664	1.8	51,000	0.21	189
1.2	1,600	2,910	1,300	2,370	1,867	0.22	178	1,967	3.7	51,100	0.22	178	1,903	1.8	51,000	0.21	189
1.2	1,700	3,060	1,300	2,370	644	0.23	187	597	10.8	51,300	0.22	187	486	4.1	54,300	0.19	201
1.2	1,700	3,060	1,300	2,370	676	0.23	187	533	10.8	51,300	0.22	187	511	4.1	54,300	0.19	201
1.2	1,700	3,060	1,300	2,370	2,072	0.20	187	1,929	11.2	53,700	0.19	187	2,132	6.2	53,800	0.18	201
1.2	1,700	3,060	1,300	2,370	2,033	0.20	187	2,141	11.2	53,700	0.19	187	1,849	6.2	53,800	0.18	201
IRON C																	
1.2	1,400	2,550	1,380	2,515	1,641	0.25	165	1,805	0.5	48,000	0.23	176	1,770	0.2	46,900	0.22	173
1.2	1,400	2,550	1,380	2,515	1,632	0.25	165	1,814	0.5	48,000	0.23	176	1,766	0.2	46,900	0.22	173
1.2	1,400	2,550	1,380	2,515	2,274	0.17	226	2,061	4.1	56,000	0.15	229	2,469	3.2	64,000	0.18	242
1.2	1,400	2,550	1,380	2,515	2,424	0.17	226	2,160	4.1	56,000	0.15	229	2,389	3.2	64,000	0.18	242
1.2	1,700	3,080	1,380	2,515	2,274	0.17	226	2,061	4.1	56,000	0.15	229	2,469	3.2	64,000	0.18	242
1.2	1,700	3,080	1,380	2,515	2,424	0.17	226	2,160	4.1	56,000	0.15	229	2,389	3.2	64,000	0.18	242
IRON D																	
1.2	1,400	2,550	1,380	2,515	1,641	0.25	165	1,805	0.5	48,000	0.23	176	1,770	0.2	46,900	0.22	173
1.2	1,400	2,550	1,380	2,515	1,632	0.25	165	1,814	0.5	48,000	0.23	176	1,766	0.2	46,900	0.22	173
1.2	1,400	2,550	1,380	2,515	2,274	0.17	226	2,061	4.1	56,000	0.15	229	2,469	3.2	64,000	0.18	242
1.2	1,400	2,550	1,380	2,515	2,424	0.17	226	2,160	4.1	56,000	0.15	229	2,389	3.2	64,000	0.18	242
1.2	1,700	3,080	1,380	2,515	2,274	0.17	226	2,061	4.1	56,000	0.15	229	2,469	3.2	64,000	0.18	242
1.2	1,700	3,080	1,380	2,515	2,424	0.17	226	2,160	4.1	56,000	0.15	229	2,389	3.2	64,000	0.18	242

* Brinell-hardness values determined with 3,000-kg load, using 10-mm ball.

will be noticed (Fig. 7) that in general the strength increases with an increase of maximum heating temperature, in the range 1,500 to 1,700° C (2,730 to 3,090° F).

28. The 1.2-inch bars made of iron A by different methods, with maximum heating temperature of 1,700° C (3,000° F), differed only slightly in their transverse breaking loads.

Table 6
CHEMICAL ANALYSES OF TRANSVERSE TEST BARS
IRON A

Di- am- eter	Temperature				Chemical composition ¹ (percent)									
	Maximum heating		Pouring		Total carbon	Gravitimetric carbon	Combined carbon	Si	P	Mn	S	Cu	Ni	Cr
	°C	°F	°C	°F										
in.	°C	°F	°C	°F										
2.2	1,400	2,550	1,300	2,370	3.86	3.10	0.76	1.43	0.45	0.52	0.027	0.33		
1.2	1,400	2,550	1,300	2,370	3.91	3.05	.86	1.43	.45	.52	.027	.33		
.75	1,400	2,550	1,300	2,370	3.91	3.03	.88	1.43	.45	.52	.027	.33		
1.2	1,500	2,730	1,300	2,370	3.84	3.11	.73	1.50	.62	.52	.033	.40		
2.2	1,600	2,910	1,300	2,370	3.74	3.14	.60	1.55	.53	.56	.046	.48		
1.2	1,600	2,910	1,300	2,370	3.83	3.28	.66	1.78	.56	.60	.030	.41		
.75	1,600	2,910	1,300	2,370	3.77	3.08	.69	1.80	.56	.60	.045	.48		
1.2	1,700	3,090	1,300	2,370	3.82	3.19	.63	1.58	.57	.63	.043	.51		

IRON B

2.2	1,400	2,550	1,380	2,515	3.24	2.45	0.79	1.46	0.45	0.35	0.068	-----	0.07	0.12
1.2	1,400	2,550	1,380	2,515	3.30	2.46	.85	1.46	.45	.35	.068	-----	.07	.12
.75	1,400	2,550	1,380	2,515	3.30	2.35	.95	1.46	.45	.35	.068	-----	.07	.12
2.2	1,600	2,910	1,380	2,515	3.16	2.37	.79	1.40	.44	.35	.076	-----	.07	.12
1.2	1,600	2,910	1,380	2,515	3.25	2.41	1.04	1.40	.44	.35	.076	-----	.07	.12
.75	1,600	2,910	1,380	2,515	3.27	2.14	1.13	1.40	.44	.35	.076	-----	.07	.12

IRON C

2.2	1,400	2,550	1,300	2,370	3.82	3.02	0.80	1.16	0.10	0.51	0.053	-----	-----	-----
1.2	1,400	2,550	1,300	2,370	3.81	3.01	.80	1.16	.10	.51	.053	-----	-----	-----
.75	1,400	2,550	1,300	2,370	3.83	2.61	1.22	1.16	.10	.51	.053	-----	-----	-----
1.2	1,400	2,550	1,380	2,515	3.73	2.95	.78	1.12	.09	.54	.055	-----	-----	-----
2.2	1,500	2,730	1,380	2,515	3.66	2.90	.76	1.10	.11	.51	.052	-----	-----	-----
1.2	1,500	2,730	1,380	2,515	3.74	2.93	.81	1.10	.11	.51	.052	-----	-----	-----
.75	1,600	2,910	1,380	2,515	3.76	2.56	1.20	1.10	.11	.51	.052	-----	-----	-----
2.2	1,600	2,910	1,380	2,515	3.61	2.77	.84	1.12	.10	.56	.054	-----	-----	-----
1.2	1,600	2,910	1,380	2,515	3.71	2.76	.95	1.12	.10	.56	.054	-----	-----	-----
.75	1,600	2,910	1,380	2,515	3.69	2.14	1.55	1.12	.10	.56	.054	-----	-----	-----
2.2	1,700	3,090	1,380	2,515	3.58	2.85	.73	1.08	.10	.51	.053	-----	-----	-----
1.2	1,700	3,090	1,380	2,515	3.80	2.70	.80	1.08	.10	.51	.053	-----	-----	-----
.75	1,700	3,090	1,380	2,515	3.63	.95	2.68	1.08	.10	.51	.053	-----	-----	-----

IRON D

1.2	1,700	3,090	1,380	2,515	2.86	2.06	0.83	2.06	0.65	0.18	0.028	-----	-----	-----
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IRON F

1.2	1,700	3,090	1,470	2,680	2.13	-----	-----	1.64	0.49	0.14	0.013	-----	-----	-----
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¹ Analyses made by R. H. Elder and Roy Deas, American Cast Iron Pipe Co., Birmingham, Ala.

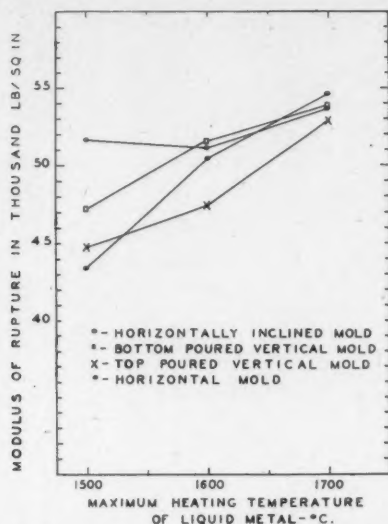


FIG. 7—RELATION BETWEEN MODULUS OF RUPTURE AND MAXIMUM HEATING TEMPERATURE. TRANSVERSE-STRENGTH TEST BARS, 1.2-INCH IN DIAMETER, OF IRON A, WERE CAST BY FOUR DIFFERENT METHODS.

29. On the basis of the breaking strength shown in Tables 4 and 5, it appears that iron A was more affected by superheating than iron C (Fig. 8), and that the modulus of rupture depended upon the cross-sectional area of the test bars and the amount of superheating (Fig. 9).

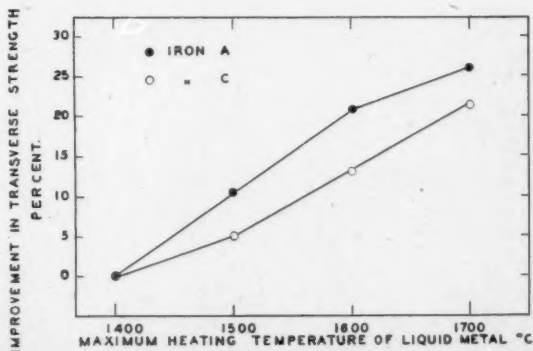


FIG. 8—RELATION SHOWING INCREASE IN TRANSVERSE BREAKING LOAD WITH MAXIMUM HEATING TEMPERATURE. THE 1.2-INCH BARS OF IRONS A AND C WERE CAST IN BOTTOM-POURED VERTICAL MOLDS.

30. (b) *Brinell Numbers*: Brinell determinations were made on disks 0.5 inch in thickness, cut from broken sections of the 1.2-inch bars adjacent to the fracture. Impressions with a 10-mm ball, under 3,000-kg load, were made in the center and mid-way between the center and periphery of the specimen. In general, the Brinell number increased with increase of maximum heating temperature.

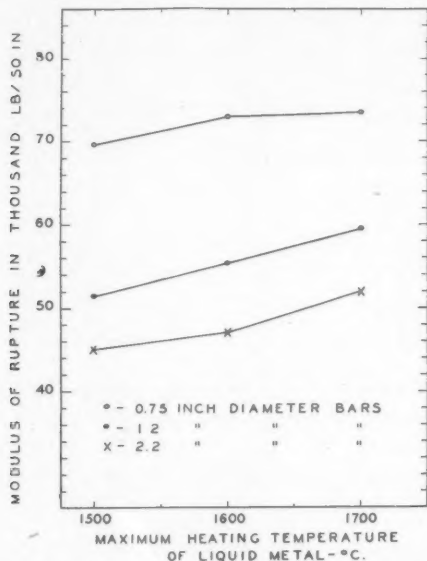


FIG. 9—RELATION BETWEEN MODULUS OF RUPTURE OF TRANSVERSE-STRENGTH TEST BARS AND MAXIMUM HEATING TEMPERATURE. IRON C WAS CAST IN BOTTOM-POURED VERTICAL MOLDS.

Structure

31. It is well known that the composition of cast iron is only one criterion of its physical properties, and that a knowledge of the structure is necessary for adequate information.

32. Cross sections of the 1.2-inch bars, cut perpendicular to the length, were examined microscopically. Sulphur prints were also made of these specimens to determine the primary structure of the irons. By the term "primary structure" is meant that structure which is formed during solidification and not the structure revealed by the fracture.

33. No significant difference in microstructure was found in the test bars of the same iron made by different methods. As is to be expected, those irons with the higher strength had finer graphite particles and finer pearlite.

SUMMARY

34. In preparing transverse-strength test bars of cast iron, freedom from burnt-on sand and other surface defects is very important.

35. A method of casting transverse-strength test bars in green-sand molds, consisting of a mixture of 8 parts of iron molding sand to 1 part of sea-coal, tempered to approximately 7 per cent of moisture, with the surface of the mold cavities swabbed with a carbonaceous nongraphitic material, has been found satisfactory in preparing test bars having superior surface characteristics.

36. Five types of cast irons heated to maximum heating temperatures of 1,400° C (2,550° F); 1,500° C (2,730° F); 1,600° C (2,910° F); and 1,700° C (3,090° F), respectively, and then cooled to a temperature of 150° C (270° F) above the liquidus temperature were poured directly from the high-frequency induction furnace into transverse-strength test-bar molds.

37. Four methods of molding test bars of various diameters were employed; bottom-poured vertical mold, top-poured vertical mold, horizontal mold, and horizontally inclined mold.

38. The temperatures of the molds after casting test bars were measured. The data obtained do not indicate that the temperature attained by the molding material between the different diameter test bars was sufficiently high to influence the physical properties of the bars to any appreciable extent as the maximum temperatures of the mold were well below the critical temperature of the iron.

39. Vertically cast bars, particularly those which were bottom-poured, were much more uniform in diameter than bars cast in horizontal or horizontally inclined molds. The bars of iron A made by different methods, with a maximum heating temperature of 1,700° C (3,090° F), differed only slightly in the transverse breaking loads.

40. The effect of maximum heating temperature on the strength and hardness of the transverse-strength test bars made by four methods was studied. In general, the strength and hard-

ness of all the bars investigated increased with increase of maximum heating temperature.

41. No essential differences in the primary structure or in the microstructure of test bars of the same composition and size, but cast by different methods, were revealed.

42. A finer primary structure, and finer graphite and pearlite constituents, were found to be associated with higher transverse strength.

ACKNOWLEDGMENT

43. The authors express their appreciation and thanks to L. D. Jones, senior molder, for the assistance rendered by him in this investigation.

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- ⁸ Franz Roll, Das Primärgefüge des grauen Gusseisens, Arch. Eisenhüttenw., vol. 8, no. 3, pp. 129-130 (Sept. 1934).

DISCUSSION

Presiding: S. C. MASSARI, Association of Manufacturers of Chilled Car Wheels, Chicago.

G. P. PHILLIPS¹: (*Submitted as Written Discussion*) The writer was particularly interested in the results given by the authors on methods of preparing transverse test bars in view of work done by him and published in the Transactions of the A.F.A. for 1934.

The use of a green sand molding material containing seacoal covered with a carbonaceous nongraphitic material as a "facing" to obtain clean smooth bar surfaces is of interest as the importance of obtaining such surfaces is self evident.

In comparing the test results obtained by the authors on their horizontally cast and bottom poured vertically cast bars the writer has computed the triangular resilience for the results given in Table 5 of the paper for the 1.20 in. diameter bars. For convenience in comparing the results the average transverse load, deflection, resilience and Brinell hardness for each set are given below:

COMPARISON BETWEEN HORIZONTALLY CAST AND BOTTOM POURED
VERTICALLY CAST 1.20 IN. DIA. BARS OF TABLE 5.

Horizontally Cast				Vertically Cast			
Load Lbs.	Defl. Inch	Resilience In.-Lbs.	Brinell	Load Lbs.	Defl. Inch*	Resilience In.-Lbs.	Brinell
1632	0.18	147	176	1784	0.17	152	183
1899	0.22	209	178	1946	0.21	204	189
2053	0.20	205	187	2030	0.18	183	201
1636	0.25	204	165	1852	0.25	231	172
2349	0.17	200	236	2416	0.19	229	244

In the first two cases the loads for the horizontally cast bars are less than those for the vertically cast but the reverse is true of the deflections resulting in about equal triangular resilience. In the third case the horizontally cast bars were superior to the vertically cast while in the last two the vertically cast bars were superior. In all cases the vertically cast bars were harder indicating possibly slower pouring and more rapid cooling of the vertically cast bars.

The authors state that the horizontally cast bars followed the A.S.T.M. proposed methods of casting bars. The method in question was originally given by the writer and the use of a riser was specified as shown on page 502 of the A.F.A. Transactions for 1934. The authors apparently used a rather small diameter "flowoff" only which would do little if any feeding.

This is mentioned since the writer obtained higher strength values with horizontally cast bars as compared with vertically cast top poured bars in a majority of cases and also found the horizontally cast bars to be more nearly true to pattern size than were the vertically cast bars.

The data given by the authors on the effects of superheating in Table 4 of their paper show the following for irons A, B and C for the 1.20 in. diameter bars.

¹ Metallurgist, International Harvester Co., Chicago.

Maximum Heating Temp. ° F.	Average Transverse Load-Lbs.	Deflection Inch	Triangular Resilience In-Lbs.	Brinell
IRON A				
2550	1614	0.24	194	166
2730	1784	0.17	152	183
2910	1946	0.21	204	189
3090	2030	0.18	183	201
IRON B				
2550	2316	0.25	289	210
2910	2660	0.26	346	214
IRON C				
2550	1852	0.25	231	172
2730	1936	0.28	271	173
2910	2084	0.27	281	190
3090	2247	0.25	281	187

As Iron A was progressively super-heated, the transverse load increased as did the Brinell hardness. The deflection decreased in varying degree. The optimum strength properties apparently were secured with the metal super-heated to 2910 deg. F. Above that temperature the resilience decreased.

Iron C showed increased transverse strength with first an increase and last a decrease in deflection with increasing super-heating temperatures, whereas the resilience apparently reached a maximum at 2910 deg. F. as was the case with iron A.

Both irons A and C were very high total carbon irons. The Brinell hardness of iron C did not increase progressively with increasing super-heating temperatures. Iron B also showed improved strength properties after superheating to 2910 deg. F.

The present writer's experience with effects of super-heating cupola melted iron, tapped at over 2800 deg. F., was given in THE FOUNDRY of August, 1935. His results showed that super-heating of steel-mix alloy irons resulted in a consistent decrease in physical properties whereas an iron made with a straight pig iron-scrap mixture was benefited by super-heating.

A. I. KRYNITSKY and C. M. SAEGER, JR., (*Written reply to discussion by G. P. Phillips*): In reply to Mr. Phillips' discussion the authors wish to state that the resilience data were not considered, as the conventional string-over-pulley method was employed in measuring the deflection. It is probable that the deflection values obtained were not of the degree of accuracy necessary to obtain reliable resilience values. At the present time an entirely different method for measuring deflection is being employed and, it is believed, that data of the degree of accuracy necessary for the computation of resilience values are obtained. As may be noted in Fig. 5 the method of gating the horizontal and horizontally inclined bars was somewhat different from that described in the A.S.T.M. tentative specifications for gray-iron castings. The risers used for the 1.2-in. bars were 0.75 in. diameter, 7.5 in. high instead of the A.S.T.M. proposed riser 1¾ in. diameter at the bottom increasing to 1¼ in. at the top, 6 in. high. Possibly the difference in the size of the risers may have had some in-

fluence on the results obtained. However, the bottom poured vertically cast bars are not provided with any riser for feeding other than a small orifice (0.6 in. diameter) at the bottom. It is difficult to believe that these vertically cast bars were poured more slowly and cooled more rapidly than the horizontally cast bars using filter cores. Mr. Phillips' observation on superheating of steel-mix alloy irons is very interesting.

W. W. KERLIN², (*Submitted as written discussion*): Messrs. Krynit-sky and Saeger have made a valuable contribution to the effect of superheating on the physical properties of the gray iron transverse bar as well as giving us definite information as to how much better one method of casting is over another. By holding the variable of pouring temperature constant by cooling their melts to the same point, with relation to the liquidus, their conclusions may be based on the factor of superheating alone. This clears the way for a research on pouring temperatures and their effect on physical properties; particularly in those irons where there is an appreciable precipitation of secondary cementite.

This commentator believes that the statement made in paragraph 29 "On the basis of the breaking strength shown—it appears that iron A was more affected by superheating than iron C —" could be extended. Consideration of the data in Table 4, and Fig. 8, does show that the increase in transverse strength in A was 25 per cent as compared with 20 per cent in C but in the case of A deflection went down and brinell hardness went up. In iron C, however, deflection remained essentially the same with only a slight increase in brinell. When toughness and resiliency are considered it would appear that these additional facts point to a net improvement in iron C which is equal if not greater than A.

Since this paper is a valuable contribution to the literature growing up around A.S.T.M. specifications on gray cast iron, the above comment is intended solely to illustrate a point frequently not fully appreciated when interpreting A.S.T.M. Specification A-48-36. It is important that casting users exercise the prerogative given them in this specification to supplement minimum deflection values when ordering castings which are to be free from brittleness under dynamic loads in the critical sections that these test bars represent.

C. M. SAEGER, JR.: In regard to Mr. Kerlin's discussion, the only point I might add is relative to his suggestion for a study of the effect of different pouring temperatures on transverse properties. That type of an investigation is now in progress at the Bureau. We have some very interesting information and I hope to be able to present it to the Association, possibly this coming year.

DR. JAS. T. MACKENZIE³: Just after this work was published, I obtained from Mr. Saeger one-half of each one of those bars, turned them down for tensile tests, data for which are shown in the Table 7, and plotted the results which are shown in Figs. 10 to 14.

Fig. 10 shows the modulus of rupture and the tensile strength. Below are the Brinells, which are plotted against the maximum melting temperature. These are the only values we had. It can be seen that the tensiles

² Meehanite Metal Corp., Pittsburgh, Pa.

³ American Cast Iron Pipe Co., Birmingham, Ala.

Table 7

BarMark	Load Lbs.	Diameter in Inches	Tensile Strength Lb. per Sq. In.
1-A-Top	11,520	.808	22,480
1-A-Bottom	11,610	.808	22,620
3-B-Top	14,470	.803	28,560
3-B-Bottom	13,260	.798	26,520
4-H-Top	13,970	.799	27,890
4-B-Bottom	15,260	.803	30,120
5-A-Top	19,060	.808	37,180
5-A-Bottom	19,300	.808	37,560
6-A-Top	20,250	.803	39,970
6-A-Bottom	21,340	.803	42,120
7-B-Top	15,680	.805	30,800
7-B-Bottom	17,720	.808	34,550
8-I-B-Top	14,600	.803	28,810
8-I-B-Bottom	14,060	.805	27,620
8-H-B-Top	12,930	.773	27,530
8-H-B-Bottom	12,940	.801	25,680
8-V-B-Top	14,280	.802	28,280
8-V-B-Bottom	14,520	.804	28,620
8-T-A-Top	13,380	.800	26,600
8-T-A-Bottom	13,640	.800	27,110
8-V-B-Top	14,280	.802	28,280
8-V-B-Bottom	14,520	.804	28,620
8-T-A-Top	13,380	.800	26,600
8-T-A-Bottom	13,640	.800	27,110
11-T-A-Top	13,940	.803	27,520
11-T-A-Bottom	13,940	.798	27,880
11-V-B-Top	12,660	.802	25,080
11-V-B-Bottom	14,170	.802	28,070
11-H-B-Top	13,190	.808	25,740
11-H-B-Bottom	13,500	.809	26,250
11-I-A-Top	13,650	.796	27,420
11-I-A-Bottom	13,710	.800	27,280
12-H-A-Top	13,420	.807	26,200
12-H-A-Bottom	13,010	.805	25,600
12-V-A-Top	16,780	.804	33,070
12-V-A-Bottom	16,620	.800	33,080
12-T-A-Top	16,560	.805	32,530
12-T-A-Bottom	16,290	.801	32,300
12-I-B-Top	14,680	.809	28,540
12-I-B-Bottom	15,250	.808	29,720
14-H-A-Top	19,950	.802	39,500
14-H-A-Bottom	19,210	.772	41,050
14-V-A-Top	22,170	.805	43,550
14-V-A-Bottom	21,930	.802	43,450
14-T-A-Top	20,250	.798	40,980
14-T-A-Bottom	21,220	.793	42,980
14-I-A-Top	19,460	.804	38,330
14-I-A-Bottom	19,960	.803	39,400
16-I-A-Top	14,890	.807	29,150
16-I-A-Bottom	14,580	.810	28,300
16-H-A-Top	13,960	.801	27,710
16-H-A-Bottom	12,920	.806	25,310
16-T-A-Top	14,590	.801	28,970
16-T-A-Bottom	14,540	.797	29,150
16-V-B-Top	14,650	.805	28,780
16-V-B-Bottom	14,170	.800	28,200

do show quite a difference on a high temperature and very little difference on the low temperature, whereas the transverse results are just the opposite.

Fig. 11 shows the Brinell hardness, modulus of rupture, and tensile strength plotted against the carbon equivalent. It is obvious that the carbon equivalent is more important than superheating except on the high carbon iron.

Fig. 12 shows the modulus of rupture plotted against the tensile strength and it will be noted that the curve is very steep. In other words, the tensile strength increases faster than the modulus of rupture, as all previous work has shown.

Fig. 13 shows some results that we have obtained, giving the effect of pouring temperature. Here we are taking the average as 100 per cent, and the bars are plotted against the respective percentages that were obtained at each temperature. It will be noted that there is a very clear indication that the irons improve from very cold to medium and then fall again. It is to be noted that No. 2290 was poured almost 50 degrees above the liquidus and at 320 above, but there is a very distinct indication that 175

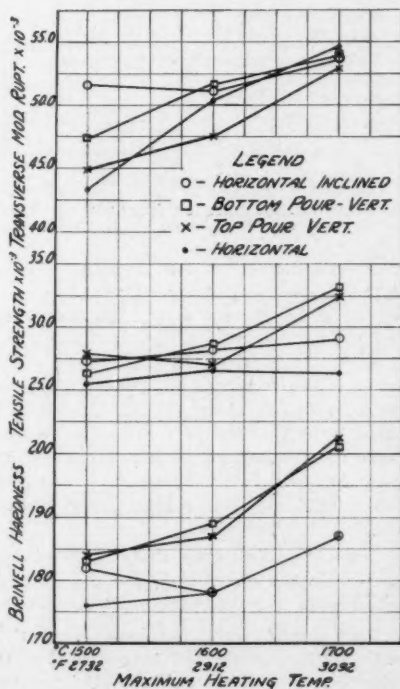


FIG. 10—EFFECT OF MOLDING METHOD AND SUPERHEAT ON IRON A.

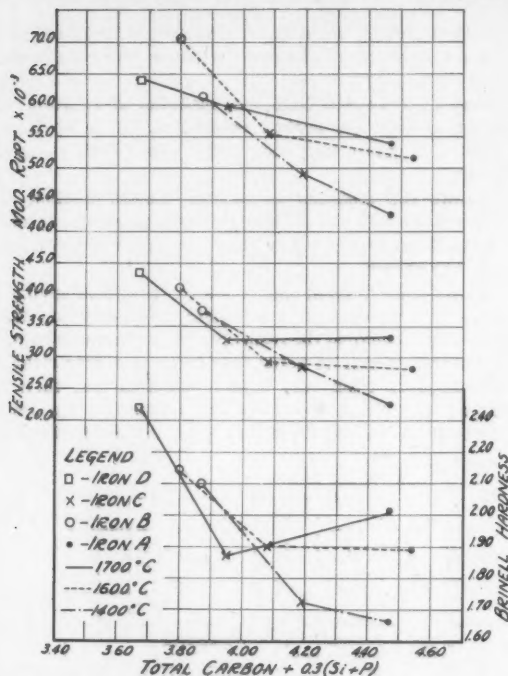


FIG. 11.—BRINELL HARDNESS, MODULUS OF RUPTURE AND TENSILE STRENGTH PLOTTED AGAINST CARBON EQUIVALENT.

is the best pouring temperature. It has nothing to do with superheat, although that might change the pouring temperature.

Fig. 14 shows the percentage of spread as against the temperature above the liquidus. These marked "gang" are poured by Mr. Saeger's method, 4 bars, 2 in. x 1 in. x 26 in., in a flask, and those marked "individual" were made one in a flask and top poured. It is to be noted that the percentage spread drops to about the 100-150 degree point and that the spread increased on both ends of the pouring temperature. These individual bars were poured through an individual pouring basin, just a small cup on top of the test bar mold, with, I believe, about a $\frac{3}{8}$ -in. sprue, and the results, while showing a larger total spread, have roughly the same tendency.

MR. SAEGER: I would like to state that I appreciate very much the work that Dr. MacKenzie has done. I believe the tensile values showed that the irons are improved by raising the maximum heating temperature.

F. J. WALLS⁴: Mr. Saeger, have you done any work relative to the uniformity of hardness throughout the length of the transverse bars, the top section, the bottom section in the case of pouring vertically, or

⁴ Metallurgist, International Nickel Co., New York, N. Y.

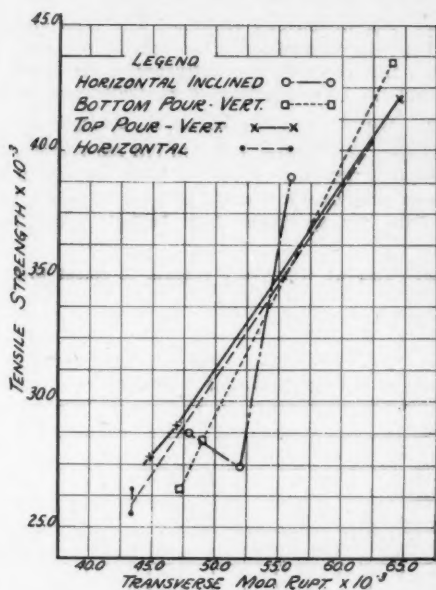


FIG. 12—MODULUS OF RUPTURE PLOTTED AGAINST TENSILE STRENGTH.

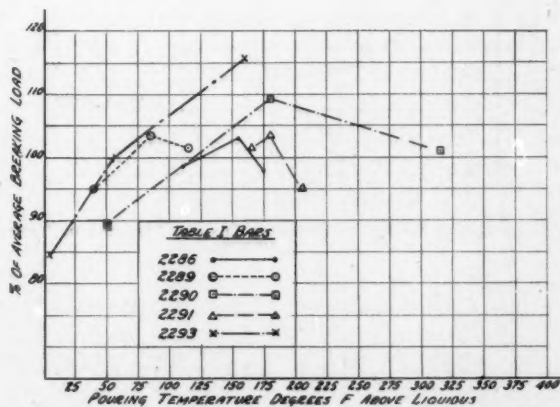


FIG. 13—EFFECT OF POURING TEMPERATURE ON AVERAGE BREAKING LOAD.

in the horizontal section, and the gate. Was there uniformity in Brinell throughout the length of that bar?

MR. SAEGER: No, we haven't sectioned any bars and measured the uniformity of hardness throughout the length of the bar.

MR. WALLS: Did you find any difference in the tensile strength between the top and the bottom halves of vertically poured bars.

MR. SAEGER: We did not run the tensile strengths on the bars.

DR. MACKENZIE: Mr. Saeger, can you tell me whether all the tensile bars we obtained from you were from the same location in each cast bar. The tensile checks were excellent and I did not know but what we might have obtained from you specimens from both tops and bottoms of the original bars.

MR. SAEGER: Yes, we were very careful to select them all from the same location.

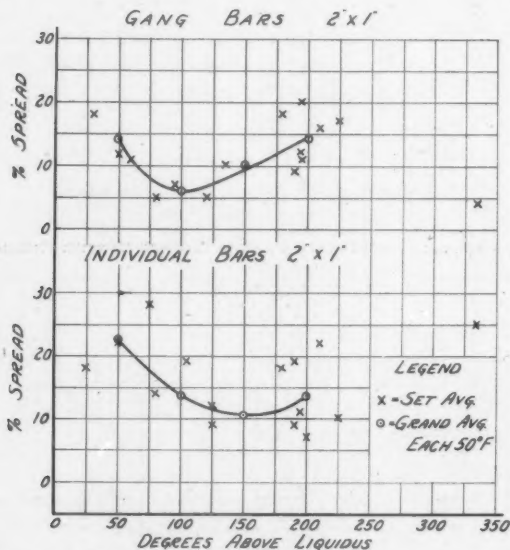


FIG. 14—PERCENTAGE OF SPREAD OF BREAKING LOAD AS AFFECTED BY TEMPERATURE ABOVE LIQUIDUS.

Cast Iron Suitable for Nitrogen Hardening

By J. E. HURST*, LICHFIELD, STAFFS, ENGLAND

Abstract

Alloy cast irons suitable for nitrogen hardening are essentially alloy cast irons containing aluminum and chromium. Typical analyses and mechanical test results are summarized. The data being given are for both sand cast and centrifugal cast material. The hardening and stabilizing treatments are listed. Machinability is discussed as of importance. Details of the nitrogen hardening process are discussed in detail with furnace considerations reviewed. The length of the nitriding process is stated to be from 40 to 90 hours according to requirements. Where some surfaces are to be left soft for subsequent machining operations, these surfaces are protected by various kinds of coatings which are discussed. General details of procedure in the preparation of articles for treatment are outlined. Further sections of the paper take up heat treatment, the nitrogen hardened surface, chemical composition, microstructure and mechanical properties and applications.

1. The nitrogen hardening process is a case-hardening process and provides a method of surface hardening both steel and cast iron articles of suitable alloy compositions. The principles involved in the process are now well known in that they consist essentially of submitting the articles to the action of anhydrous ammonia gas for a suitable period of time at a low temperature in the neighborhood of 932° F. (500° C.). The development of this process is due to the researches (about 1920) of Dr. Adolphe Fry, connected with the firm of Krupps in Germany.¹

2. Experimental work in the production of cast iron suit-

* Technical Director, Sheepbridge Stokes Centrifugal Castings Co., Ltd., Chesterfield and Bradley and Foster Co., Ltd., Darlston, England.

¹A. Fry, *Kruppsche Monatshefte* 1923, Vol. 4, and *Stahl Und Eisen*, 1923, Vol. 43.

NOTE: This paper was presented at a session on Cast Iron at the A.F.A. Milwaukee Convention in 1937.

able for nitrogen hardening was commenced in 1928 by the companies with which the writer is connected, and the extension of this process to cast iron is due to them.² The first castings made commercially were oil engine cylinder liners, which were put into operation in the month of October 1928. Since that date, continued experimental and development work has resulted in the further perfection of the alloy cast irons and the manufacturing processes for the production of articles which can be super-hardened in this manner.

ALLOY CAST IRON SUITABLE FOR NITROGEN HARDENING.

3. The alloy cast irons suitable for nitrogen hardening which have come to be known as "Nitricastiron" are essentially alloy cast irons containing aluminum and chromium. In this respect they are analogous to the aluminum chromium series of alloy steels introduced for this purpose and known as Nitrallloy Steels. Typical analyses and mechanical test results have been described by the author,³ and are summarized in a convenient form in Table 1.

4. The chemical compositions of the material both in the centrifugally cast and sand cast conditions are given, as are also the mechanical properties after various heat treatments. All the tests enumerated in the table have been carried out on ring form specimens in accordance with the B.S.I. Specifications No. 5004, and all the hardness determinations with the Firth Hardometer using the diamond indenter and a 30 kilogram load. The chemical analyses were made on material in the annealed condition after treatment at a temperature of 1742° F. (950° C.) followed by slow cooling in the furnace.

HARDENING AND STABILIZING TREATMENTS

5. The hardening and stabilizing treatment consisted of oil quenching from a temperature of 1598° F. (870° C.) followed by reheating to 1112° F. (600° C.) for a period of one hour, cooling slowly from this temperature in still air. The nitrogen hardening treatment was carried out for a period of 90 hours at a temperature of 950° F. \pm 9° F. (510° C. \pm 5° C.) in ammonia

² A. Fry, The Iron & Steel Institute, 1932, Vol. 1, p. 210.

³ J. E. Hurst, The Iron & Steel Institute, 1932, Vol. 1, p. 223.

gas, the degree of dissociation being maintained at a value of 30 percent. The measured depth of penetration of the hardening effect was 0.016 to 0.018 in. and 0.015 in. in the centrifugal and sand cast specimens respectively.

PROPERTIES

6. In examining the properties detailed in Table 1 it is clear that this alloy possesses a high modulus of elasticity. This value changes slightly in an upward direction with each treatment. The difference between the centrifugally cast and sand cast conditions will be noted also.

Table 1

COMPARISON OF PROPERTIES OF CENTRIFUGALLY CAST AND SAND CAST
NITROGEN HARDENING CAST IRON

<i>Analysis</i>	<i>Centrifugal</i>	<i>Sand Cast</i>
	Per Cent	Per Cent
Total Carbon	2.65	2.62
Graphite	1.10	1.63
Combined Carbon	1.55	0.99
Silicon	2.58	2.44
Manganese	0.61	0.60
Sulphur	0.07	0.075
Phosphorus	0.096	0.098
Chromium	1.69	1.58
Aluminum	1.43	1.37
<i>Modulus of Elasticity</i>	lb. per sq. in.	lb. per sq. in.
As Cast	22,500,000	19,500,000
Annealed	23,700,000	19,700,000
Hardened and Stabilized	23,000,000	19,200,000
Nitrogen hardened	23,500,000	20,100,000
<i>Tensile Strength</i>	lb. per sq. in.	lb. per sq. in.
As Cast	55,000	44,350
Annealed	66,750	51,300
Hardened and Stabilized	66,100	64,100
Nitrogen hardened	66,750	53,500
<i>Permanent Set</i>	Per Cent	Per Cent
As Cast	2.5	6.1
Nitrogen hardened	4.75	9.7
<i>Firth Diamond Hardness</i>	No.	No.
As Cast	418	340
Annealed	302	269
Hardened and Stabilized	302	300
Nitrogen hardened	982	904

7. The tensile strength is accompanied by a distinct increase due to heat treatment and the nitrogen hardened specimens show a slight falling off from the strength level attained as a result of heat treatment. The change in hardness of the material due to heat treatment is clearly indicated.

8. The properties of the alloy in the sand cast condition have approximately the same tendencies as those of the centrifugally cast material. In magnitude the values of the modulus of elasticity and tensile strength are lower than those of the same material centrifugally cast. The permanent set values are higher, and in the "as cast" and annealed condition the hardness is lower. In the hardened and stabilized condition the hardness more nearly approaches the hardness of the same alloy centrifugally cast. In the sand cast condition the alloy is somewhat less stiff and less strong than the centrifugally cast material. It is necessary to add that the centrifugally cast material has been prepared by pouring the metal into rotating metal molds, and full details of this process have been described by the author elsewhere.⁴

9. Some further properties of this alloy cast iron in the centrifugally cast condition have been determined as follows:

Specific Gravity, 7.4 approx.

Specific Heat between 0.12 and 0.14.

Coefficient of Expansion

1.09×10^{-5} temperature range 30 to 100°C. 86 to 212°F.

1.17×10^{-5} temperature range 100 to 200°C. 212 to 392°F.

1.35×10^{-5} temperature range 200 to 300°C. 392 to 572°F.

1.5×10^{-5} temperature range 300 to 400°C. 572 to 752°F.

10. *Machinability.* Amongst the further properties that of machinability is of some importance. The Brinell hardness of this alloy in the annealed condition lies between 260 and 300 and the material is somewhat harder to machine than ordinary cast irons. It is found that it can be machined satisfactorily with Widia tipped tools or Stellite. Annealed centrifugally cast Nitricastiron castings were machined in the lathe at a speed of 70 feet per minute with a depth of cut of $\frac{1}{8}$ in. to $\frac{3}{16}$ in. and a feed of 40 cuts per inch using Widia tipped tools. The machining speed of sand cast Nitricastiron using the same kind of lathe and tools was 90 feet per minute, with the same depth of cut and a feed of 30 to 40 cuts per inch.

⁴ J. E. Hurst, Metallurgia, Jan. 1930 and elsewhere.

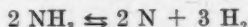
THE NITROGEN HARDENING PROCESS

11. In the industrial nitriding of Nitricastiron articles, electrical heating is adopted. The furnace used is of the resistance type and is provided with automatic temperature regulation. The parts to be nitrided are placed in a gas tight box made of heat resisting steel. The parts are placed loosely in the box without any special packing material. Individual layers can be separated by means of nickel wire netting and care should be taken in packing the boxes to allow of free circulation of the anhydrous ammonia gas. The box is provided with inlet and outlet tubes for the gas and a pyrometer tube projecting into the center of the box is used for accurate control of the temperature.

12. Various other types of furnaces have been devised for the nitrogen hardening operation in which the box is dispensed with and effective circulation of the ammonia gas secured by means of fans. These furnaces are equally suitable for the treatment of nitrogen hardening cast iron articles. Anhydrous ammonia gas is supplied to the box from a cylinder of liquid anhydrous ammonia and with the current of gas flowing the temperature of the box is raised to 932° F. (500° C.) and maintained at this value plus or minus 9° F. (5° C.). The pressure of the ammonia gas in the box is slightly above atmospheric from 1/2 in. to 1 in. water gauge, and governed by a water bottle through which the exit gases are led.

13. The length of time of the nitriding process varies from 40 to 90 hours according to requirements. When the period of nitriding is completed the furnace is allowed to cool down quickly to 698° F. (370° C.) with the current of ammonia passing. The box is then taken out of the furnace and the parts removed as soon as they are cool enough to handle.

14. Control of the process is exercised through the extent of dissociation of the ammonia. The ammonia dissociates to a certain extent into nitrogen and hydrogen according to the reaction:



15. The exit gases leaving the furnace consist therefore of hydrogen, nitrogen and undissociated ammonia. The ammonia gas is very soluble in water and advantage of this is taken in determining the extent of dissociation. A special form of pipette has been designed for this purpose. A value of 30 per cent ammonia dissociated is found to be the most desirable condition. The exit

gases are periodically tested throughout the operation. If the extent of dissociation is greater than 30 per cent the gas flow should be increased, while if it is less than 30 per cent the rate of flow should be decreased.

PROTECTION OF SURFACES

16. Very frequently articles for case hardening require some surfaces to be left soft for subsequent machining operations, the cutting of threads, keyways, etc. The protection of such surfaces from the hardening effect is commonly done by tinning. Pure tin or tin solder is generally used for this purpose. Although such solders melt at a lower temperature than the nitriding temperature, a sufficient amount will adhere by reason of surface tension and will supply ample protection.

17. In the application of tin the parts are thoroughly cleaned and a flux of hydrochloric acid (killed) applied. The articles are then dipped into a bath of molten solder or tin and kept there sufficient time for the tin to adhere. The excess of tin can be shaken or brushed off with a wire brush on removal from the bath.

18. Nickel plating to a depth of 0.0005 in. has been found effective in preventing nitriding.

19. Experiments have been made with protective paints. Positive results have been obtained with paints made up of stannous or stannic oxides. These compounds decompose in the nitriding furnace to form tin.

20. Another protective paint consists of powdered aluminum and sodium silicate. This is applied with a brush to the surfaces to be protected and then allowed to dry. A hard coating is formed which can be removed after nitriding by boiling the articles followed by scratch brushing.

21. The most recent type of protective paint consists essentially of a mixture of finely powdered lead and tin suspended in an oily vehicle of animal oils. This can be applied to the articles by means of a brush or spray pistol. The fine coating of powdered lead and tin thus obtained on the surface melts at the *nitriding* temperature and thus exercises the same function as the solder applied in the manner previously described.

PREPARATION FOR TREATMENT AND RECTIFICATION

22. While for certain purposes articles can be treated in the

"as cast" condition after a good sand blasting to remove all traces of scale and dirt, for the most part the case hardening treatment is applied to articles in the finished machined condition. It will be realized that the *nitriding* treatment consists of a single operation of treating under the prescribed conditions at a temperature of 932° F. (500° C.), a temperature which is below that of visible red. No further treatment is necessary, so that articles after the single treatment may be put to immediate use.

23. The following general details of procedure in the preparation of Nitricastiron articles for treatment may be of interest:

(1) Rough machine to remove bulk of the material leaving ample allowance on all surfaces to accommodate any distortion which may occur during the stabilizing treatment. Good radii should be left everywhere and all corners should be well rounded. It is advisable to retain as much bulk of material as possible on surfaces not required to be hardened until after the hardening operation in order that the parts shall be as rigid as possible during the hardening treatment.

(2) Stabilize by heating to a temperature of 1022° F. to 1112° F. (550° C. to 600° C.) for a period of from 1/2 to 6 hours according to size and complexity of the casting. This treatment can be followed by cooling freely in still air. The purpose of this treatment is to allow the part to take its definite set to avoid and minimize distortion which might occur in subsequent nitriding. After this treatment the parts should be examined and if appreciable deformation has occurred the parts should be rectified at this stage and re-established.

(3) Finish machine and grind surfaces required to be hardened. If surfaces not required to be hardened are to be protected by tinning, this operation may be done prior to finish-machining in order that any tin adhering to the surfaces required to be hardened can be removed in the finish-machining operations. If protection is carried out by painting then this can be done after finish-machining and grinding.

(4) The nitriding process leaves no scale but merely a dull matt film which can be removed by buffing or lapping or rubbing with fine emery.

Only very slight changes in dimensions occur after this operation so that normally parts are quite satisfactorily treated after finish grinding or honing processes. In those cases where

intense accuracy of dimensions is required in the finished parts, allowance for the slight change in dimensions and subsequent rectification can be made in the finish-machining operations. The actual allowance to be made is best determined by the trial of an actual part.

(5) Final rectification can be done by grinding or honing and in these instances the amount of material removed from the hardened surfaces should not exceed 0.002 in.

(6) Where finely polished surfaces are required, it is essential that the surface should be finely polished prior to the hardening operation.

HEAT TREATMENT

24. With the object of insuring uniform machining qualities, castings in Nitricastiron are submitted to an annealing treatment by heating up to a temperature of 1742° F. (950° C.) and allowing to cool slowly. This alloy can be oil hardened and tempered and under certain circumstances the casting is heat treated in this manner after annealing and rough machining by quenching in oil from 1598° F. (870° C.), and tempering at temperatures of 1112° to 1292° F. (600° to 700° C.).

25. The tempering treatment may be prolonged to provide a stabilizing treatment intended to remove internal stresses and thus minimize distortion during nitrogen hardening. This oil hardening and tempering treatment has a very marked effect in producing a spheroidized structure and without doubt this structural condition insures excellent stability in the nitrogen-hardened case.

26. Where there is any risk of distortion it is always advisable to adopt the stabilizing treatment whether the oil hardening is or is not performed. The stabilizing treatment should be carried out after the preliminary rough machining operations by heating to a temperature of 1020° F. to 1200° F. (550° C. to 650° C.) for periods of one-half to six hours according to the size and complexity of the casting.

THE NITROGEN HARDENED SURFACE

27. The alloy, both when sand cast and when centrifugally cast, gives hardness and depth of penetration values somewhat lower than those of standard Nitralloy steel LK 3 grade; the degree of hardness attained and also the depth of penetration in

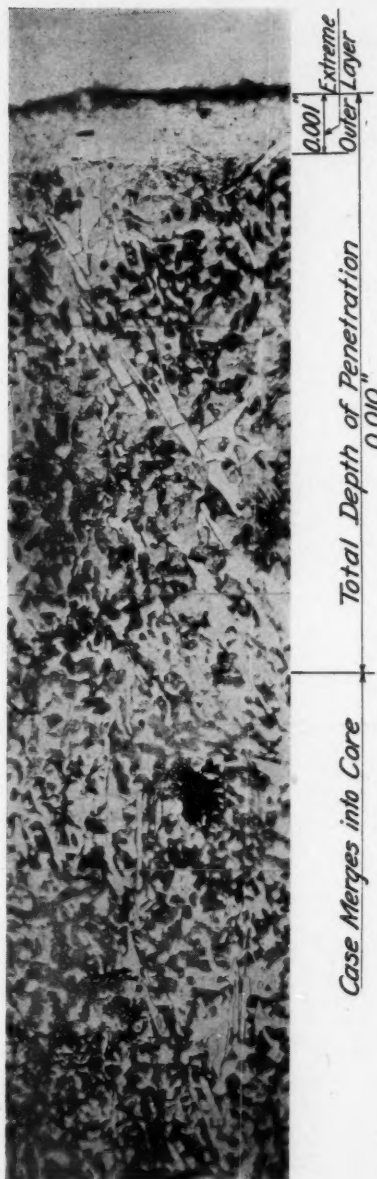


FIG. 1—SURFACE ZONE NITROGEN HARDENED MATERIAL, CENTRIFUGALLY CAST—ETCHED, PICHIC ACID—X600

the centrifugally cast specimens are slightly greater than those of the sand cast specimens.

28. An illustration of the structure of the hardened layer is given in the micrograph of Fig. 1. The nitrogen hardened layer etches darker than the core with picric acid. The carbides exist in the hardened case apparently undecomposed and an extreme outer layer which etches lighter than the hardened case can be clearly seen under the microscope and is visible in this figure. It is of general interest to note that some of the massive carbide areas in the nitrogen-hardened portion show one or more rectilinear markings in a direction at right angles to their longest axis. None of

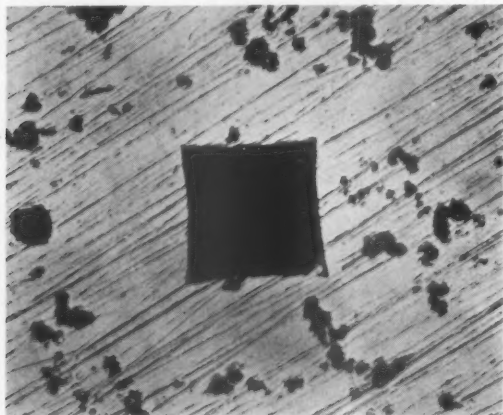


FIG. 2—DIAMOND HARDNESS IMPRESSION ON SURFACE OF CENTRIFUGALLY CAST MATERIAL—UNETCHED—x119

the carbide areas in the core appears to show these markings. Immediately underneath the extreme outer layer is a concentration of specks of a third constituent. This appears to be characteristic.

29. In all the specimens examined, the nitrogen-hardened surface is quite coherent and is not easily flaked or spalled. Under the microscope the polished surfaces of the hardened specimens show numerous small cavities. These are due to the presence of the free graphite in the surface and are illustrated in Fig. 2, which also shows a typical diamond hardness impression. The complete absence of spalling is demonstrated by this impression.

CHEMICAL COMPOSITION

30. The composition of the aluminum chromium alloy cast iron set out in Table 1 is typical of the material used in the manufacture of centrifugally cast nitrogen hardened cylinder liners.

31. The essential alloying elements are aluminum and chromium, and so far the best results both as regards maximum surface hardness and total depth of penetration are obtained when these two elements are present conjointly. Nitrogen hardening is obtained in alloy cast irons in which either of these elements are present singly.

32. The effect of silicon, manganese and phosphorous on the hardening properties of aluminum chromium alloys as used for nitrogen hardening in the centrifugally cast condition has been studied⁵.

It has been shown that the variation in silicon content has no effect upon the degree of surface hardness attained, but it does appear to have an effect upon the total depth of penetration; the higher the silicon the lower the depth of penetration.

33. In the case of phosphorus the results show that with phosphorus in excess of 0.20 per cent a reduction in surface hardness is obtained, but the total depth of penetration is not effected. Within the range examined manganese appears to be without effect either upon the degree of hardness or the total depth of penetration.

34. In this same investigation results were obtained in support of the view that the effect of chromium was in the direction of insuring greater depth of penetration rather than affecting the magnitude of the surface hardness.

35. The addition of other elements, molybdenum, titanium, vanadium, tungsten, copper and nickel have been referred to amongst others in the patent literature relating to both nitrogen hardening steels and cast irons. While a considerable amount of work still remains to be done in studying systematically the effect of these elements, it is already known that some of them are of importance and value through the influence they exert on improving the freedom from fragility of the case and the mechanical properties of the material after subjection to the nitrogen hardening treatment.

36. The element molybdenum has proved of considerable

⁵ Hurst, J. E., "Some Experiments on the Influence of Silicon, Phosphorus and Manganese on the Nitrogen-Hardening Cast Iron," (Preprint 8), 1937, Iron and Steel Institute.

value in this respect, particularly in its effect in preventing a type of temper brittleness which may appear in these alloy cast irons. This effect, particularly in the presence of nickel after the long period at the low temperature of 932° F. (500° C.) during the nitrogen hardening treatment has been referred to by the writer⁶ in his paper before the A.F.A. last year. It is by no means an uncommon practice to use molybdenum additions up to 0.6 per cent in commercial Nitricastiron.

37. A published example⁷ of the composition of aluminum-chromium-molybdenum alloy cast irons suitable for nitrogen hardening is given in Table 2.

Table 2

	Centrifugal Castings Per Cent	Sand Castings Per Cent
Total Carbon	2.5	2.9
Silicon	1.5	1.6
Manganese	0.6	0.6
Aluminum	1.25	1.0
Chromium	0.2	2.9
Molybdenum	0.6	0.75

38. In a short study of the influence of nickel⁸ it has been shown that with the presence of sufficient aluminum and chromium, nickel has no detrimental effect on the degree of hardness or depth of penetration. In the absence of aluminum the surface hardness after the nitrogen hardening treatment is most unfavorably influenced by the nickel.

39. The desire to avoid the difficulties inherent in the handling of aluminum-containing cast irons in the foundry is probably responsible for attempts to eliminate the aluminum as in the case of the following patented composition.⁹ This has the following approximate range: Total carbon 2.0 to 4.0 per cent; silicon 1.0 to 4.0 per cent; manganese 1.0 per cent max.; chromium 1.5 to 3.5 per cent. If other elements are included tungsten may be present up to 2.0 per cent, and titanium, vanadium, and molybdenum not over one per cent. After nitrogen hardening cast iron of the above general composition the Brinell hardness has been

⁶ J. E. Hurst, Foundry Trade Journal, Nov. 14, 1935, p. 372 and A.F.A., 1936.

⁷ Homerburg & Edlund, Metals & Alloys, July, 1934.

⁸ Dobrowidow and Schubert, Archiv für das Eisenhüttenwesen, Vol. 8 1934-35, p. 361.

⁹ U. S. A. Patent No. 1970082.

raised from 400 to approximately 800. This, of course, is less than that obtained with the aluminum chromium alloys.

40. The nitrogen hardening process has been extended also to the surface hardening of austenitic cast irons.¹⁰ As is well known certain austenitic cast irons possess a valuable property in that they have a high coefficient of expansion. By treatment with the nitrogen hardening process a surface hardness of up to 500 Brinell and sometimes higher can be obtained. This is of value in improving the wearing and running properties of wearing surfaces on articles manufactured in alloy cast irons of this type.

MICROSTRUCTURE AND MECHANICAL PROPERTIES

41. Abundant evidence has been obtained showing that the structural characteristics of aluminum chromium alloy cast irons are of great importance in obtaining satisfactory hardening. The

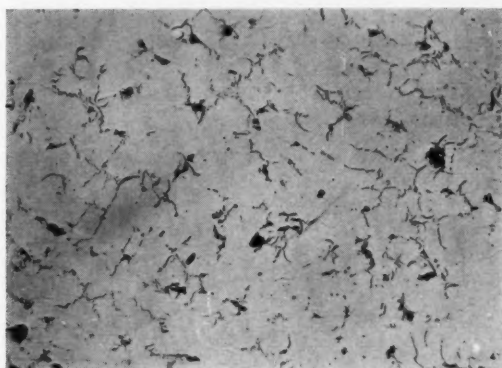


FIG. 3—GRAPHITE STRUCTURE OF CENTRIFUGALLY CAST NITROGEN HARDENING CAST IRON—UNETCHED—X110

alloy cast iron in the centrifugally cast condition, in which the structure is generally finer gives more uniformly satisfactory results than the same material in the sand cast condition. Close grain characteristics are essential and this is governed by the method in which the alloy cast iron is prepared, in addition to the chemical composition and cooling conditions.

42. In the "as cast" condition the structure shows very fine graphite plates together with substantial quantities of free carbides

¹⁰ J. E. Hurst, I.B.F. Scottish Branch, Oct. 14, 1933. (Iron & Steel Industry Nov. 1933.)

distributed in a matrix of very finely laminated pearlite. After annealing a slight increase in the amount of free graphite is obtained and the pearlite carbides become coagulated in a ferritic matrix and in the quenched and stabilized condition a completely spheroidized matrix structure is obtained.

43. The photomicrographs of Figs. 3 and 4 are typical and show the unetched structure at a magnification of 100 diameters, and the etched structure at the nitrogen hardened surface zone. This latter shows the penetration of the nitrogen hardening effect and the typical general etched structure.

44. The mechanical properties of aluminum chromium alloy cast irons prepared under the same conditions are substantially

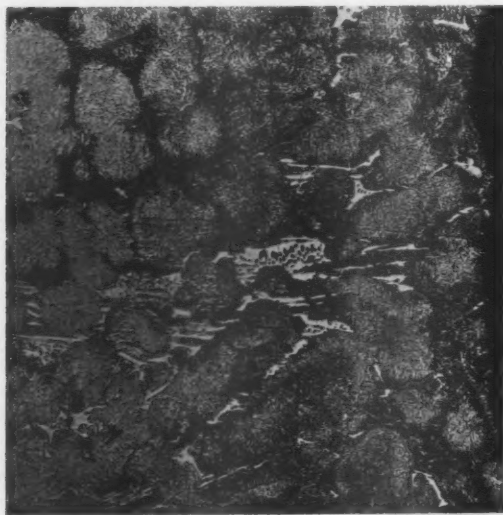


FIG. 4—SURFACE ZONE NITROGEN HARDENED SPECIMENS, SAME AS FIG. 3—ETCHED, PICTIC ACID—X200

influenced by the chemical composition, particularly in so far as this affects the condition of the carbon. This is a matter of considerable importance, as it is well known that the service behaviour of case hardened parts is in a large measure dependant upon the mechanical properties of the material constituting the core in addition to those of the case itself. This is clearly recognized in the industrial application of case hardening steels and in the standard nitralloy steels, for example a range of steels of increasing carbon

contents is provided which enables a range of properties to be obtained in the core material.

45. Similar considerations apply in the industrial applications of nitrogen hardening cast irons. The comparative mechanical properties of two compositions prepared from the same materials and by the same processes, centrifugally cast are detailed in Table 3. The essential differences in the two compositions are a lower chromium and silicon and a higher aluminum content in material B. These differences have had the effect of reducing very substantially the combined carbon content in this material in the "as cast" condition. This in turn is accompanied by a lower Brinell hardness, modulus of elasticity, tensile strength and a substantially higher permanent set value.

Table 3

COMPARATIVE MECHANICAL PROPERTIES OF TWO COMPOSITIONS

	Material	
	A	B
<i>Analysis</i>	Per Cent	Per Cent
Total Carbon	2.61	2.34
Graphite	1.50	1.99
Combined Carbon	1.11	0.35
Silicon	3.00	2.07
Manganese	0.60	0.56
Phosphorus	0.08	0.09
Chromium	1.50	0.62
Aluminum	1.48	1.70
<i>Modulus of Elasticity</i>	lb. per sq. in.	lb. per sq. in.
As Cast	24,600,000	18,800,000
Hardened and Stabilized	25,200,000	21,000,000
Nitrarded	25,000,000	19,200,000
<i>Tensile Strength</i>	lb. per sq. in.	lb. per sq. in.
As Cast	79,000	41,900
Hardened and Stabilized	80,200	47,260
Nitrarded	64,000	47,260
<i>Permanent Set</i>	Per Cent	Per Cent
As Cast	1.70	8.0
Hardened and Stabilized	1.26	2.7
Nitrarded	1.13	5.75
<i>Brinell Hardness</i>	No.	No.
As Cast	335	266
Hardened and Stabilized	335	305
Nitrarded, Surface	979	905
Nitrarded, Core	305	255

46. It is of interest to note that while these properties are improved in the direction of material *A* by hardening and stabilizing, they do not reach values of the same magnitude nor does the improvement survive the nitrogen hardening treatment and the *B* material is substantially softer, less stiff and more liable to deformation than material *A*.

SOME APPLICATIONS OF NITRICASTIRON

47. Many different types of castings in this material have been produced already, both by centrifugal casting and ordinary sand casting methods, but by far the largest commercial application at the present time is the production of cylinder liners. Large numbers of Nitricastiron liners have been fitted to various types of petrol, oil and compression ignition engines and many of these have been in service for considerable periods. Full details of the determination of the resistance to wear of Nitricastiron cylinders under actual engine running conditions have been published by the writer in a paper¹¹ before the Iron & Steel Institute.

48. In deciding upon the experimental procedure, it was considered that the available types of abrasion wear testing machines were not likely to give results of value in determining the comparative resistance of materials to wear in engine cylinders. For this reason the experiments were carried out under actual engine cylinder conditions. To obtain results of a decisive character the tests under these conditions were of very prolonged duration and actually occupied over three years, during which several individual engine tests were conducted over a running time period equivalent to 40,000 miles road running. Other tests were carried out under actual road running conditions for a similar duration. The experiments undertaken clearly duplicate actual industrial conditions, a point which is of tremendous importance when dealing with such a complex property as the resistance to wear of engine cylinders.

49. In the experiments, cylinder liners of nitrogen hardened cast iron whose surface hardness was recorded at approximately 1000 Firth diamond hardness were compared with liners of plain unalloyed cast iron, chromium alloy cast iron and nickel chromium cast iron, both of these latter being tested in the "as cast" and hardened and tempered condition. The approximate hardness of

¹¹ J. E. Hurst, The Iron & Steel Institute, 1933, Vol. 2.

these materials was 230 to 260 Brinell for the ordinary and chromium alloy cast iron in the "as cast" condition and 480 to 500 Brinell for the materials in the hardened and tempered condition. All tests were carried out for periods of 10,000 miles or multiples of this period and the cylinder wear was determined by a comparison of the maximum diameter after the test with the original diameter of the cylinder bore. Following a now common and well understood practice, the resistance to wear was expressed in miles per one-thousandth of an inch wear.

50. A strict comparison of the results obtained can be made only on the basis of equal mileages. At a mileage of 30,000, the resistance to wear of nitrogen hardened alloy cast iron compared with ordinary cast iron as used normally for cylinder liners was as 2:1 and compared with chromium alloy cast iron as 2.6:1. At a mileage of 40,000 the ratio of nitrogen hardened to chromium alloy cast iron still remained the same as 2.6:1. These results refer to tests carried out in a stationary engine.

51. In actual road tests, while the wear value in miles per 0.001 in. of wear was smaller in magnitude, at a mileage of 40,000 the ratio of nitrogen hardened to the hardened and tempered chromium alloy was found to be as 2.2:1, a figure in close agreement with the stationary engine tests. In the actual wear values the nitrogen hardened cast iron showed results of from 10,000 to 32,000 miles engine running for a wear of 0.001 in. cylinder diameter. A matter of some interest was the fact that the differences between the wear values of ordinary cast iron, alloy cast irons in the "as cast" condition, and hardened and tempered cast irons were not very large.

52. The experiments clearly demonstrate the improved wear resisting properties of the super-hard nitrogen hardened cast iron under internal combustion engine cylinder conditions. They may be used also to demonstrate the stability of the nitrogen hardened surface under these same conditions.

53. The nitrogen hardened surface is definitely corrosion resisting and from this point of view is considerably superior to ordinary cast iron. This property is one which is likely to prove of value in engine cylinder liners. In several cases already liners have been manufactured hardened externally as well as internally with the object of providing some resistance to corrosion on the cooling water side.

54. In the case of sand castings, while the development has not

been so great as in the case of centrifugal castings, quite a number of castings of different types have been produced successfully. A typical example is the valve body for the rotary valve engine described¹² by Cross. Other castings such as special cams, press tools worm castings, are typical of the type of castings for which nitrogen hardened cast iron is suitable.

55. It will be agreed that the ability to produce surfaces super-hardened in the manner described, in alloy cast iron is a discovery of far-reaching importance in the field of the metallurgy of cast iron. In its further development it cannot fail to find innumerable applications in the construction of wearing parts in all types of machinery. Already the application of this material to cylinder liners is giving results beyond the imagination of engineers even six or seven years ago. The facility of hardening castings in this manner is one of the several developments which have done so much to place the metallurgy of cast iron on the level of that of steel.

ACKNOWLEDGMENT

56. Finally, the author would like to take this opportunity of thanking the Directors of the Sheepbridge Stokes Centrifugal Castings Co. Ltd., and Bradley & Foster, Ltd., for permission to publish the results embodied in this paper.

DISCUSSION

Presiding, Dr. Jas. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.

C. O. BURGESS¹: I am not nitriding cast iron but feel that Mr. Hurst is to be complimented on his exposition of the development of nitri-cast-iron. It might be pertinent to note that care should be taken in casting these liners to avoid porous areas on the finished bore. Normally, this can be taken care of by allowing enough finish material so that some machining can be done before nitriding. In case there is fine porosity, on nitriding you may get a small raised area directly above a pore or void. This is evidently due to the fact that the void allows the nitriding gas to penetrate into that particular area and swelling results. A white layer is found around the void similar to the extreme outer layer of the case shown in Fig. 1 of Mr. Hurst's paper.

R. F. HARRINGTON²: Our own company is licensed under the Nitralloy patents to make nitridable iron and we are furnishing castings capable of

¹² R. C. Cross, Proceedings Institute of Automobile Engineers, Vol. XXX 1935-1936, p. 311.

¹ Metallurgist, Union Carbide and Carbon Research Laboratory, Niagara Falls, N. Y.

² Metallurgist, Hunt-Spiller Mfg. Co., Boston, Mass.

being nitrided, but I believe the largest producer on a production scale is the Forging and Castings Company with their sleeve castings. We did some of the initial experimental work in the production of nitridable iron with a composition somewhat after the style as noted by Mr. Hurst. Particularly for castings of various sizes and shapes and cross-sectional area, the proper gating in order to get a clean casting and one that would machine free of defects was a very difficult problem. The answer, I believe, is largely based upon the need of permitting the metal to enter the mold in such a manner that there is a minimum of disturbance. I think that is the secret of pouring, at least for industrial types of castings, when you have aluminum present in the metal. That has been our experience, anyway, and we have it well in hand, but it was a matter of a year or two before we developed a technique that would permit of the pouring of relatively intricate or different types of castings with the aluminum content necessary for the nitridable iron.

CHAIRMAN MACKENZIE: Do you know how much higher temperature this has to be poured at, roughly, than ordinary iron?

MR. HARRINGTON: We do not pour it at any higher temperature. It is wholly a question of preparing the mold with the greatest care as to cleanliness and then gating it in such a manner that all the metal will enter the mold with the minimum disturbance. If there is any disturbance at all, then you have these inclusions that make it impossible to get a clean casting on machining. A previous speaker made particular reference to the fact that if there was any porous area, like a shrinkage area, this bubble effect resulted. It looks much like pebbled leather when there is any area of shrink, so you have to be careful to avoid a hot spot at your gate, because near that hot spot, after machining, there may be a slight shrinkage area or openness and you will get a defective casting after it is nitrided.

There are two important factors. The one is letting the metal enter the mold very carefully and gradually and the other is having absolute cleanliness.

CHAIRMAN MACKENZIE: How many rejects do you get from this process?

MR. HARRINGTON: We are not making them in numbers to the extent that we have any very good records to answer this question. For example, we may make two castings or four or six of an industrial type. The casting may weigh anywhere from 1000 to 1500 pounds or it may be down to 200 or 300 pounds, but, once the technique is developed on a particular casting, I think it is reasonable to expect rejections not greater than 10 per cent.

G. P. PHILLIPS²: I believe it would be well to point out that Mr. Hurst's experience with hardened and tempered liners apparently does not coincide with the experience that we have had in this country. Most of you here will recall Mr. Eddy's paper³ presented before this Association a few years ago, in which he gave wear resistance of the hardened,

² Metallurgist International Harvester Co., Chicago.

³ W. P. Eddy, Jr., Heat Treated Gray Iron Cylinder Liners, Trans. A.F.A. vol. 42 (1934) pp. 129-147.

tempered liners in use in bus engines and compared it to wear resistance of cylinder blocks made with highly alloyed iron, with good Brinell hardness, and by that I mean up around 230 Brinell. Mr. Eddy reported wear resistance in the case of the hardened, tempered liners about three times that of the material in the cylinder blocks.

In our own experience, we can verify that same experience with tractor engines. We will even go higher and say three to five times the life with the hardened liners as compared to the as cast liners.

We have run a few tests with nitrogen hardened liners in Diesel engines and tractors, all the tests being in service, and have not as yet found the difference in wear resistance between the hardened and tempered liners and the nitrogen hardened liners that Mr. Hurst has reported. I should say, too, that we have not obtained the hardness that he obtained, of around 900 Brinell. Perhaps at some time in the future we may find that nitrogen hardened liners have more virtues than we have found up to the present time, but we do know very definitely that hardened and tempered liners, properly made, will outwear liners in the "as cast" condition about three to five times.

J. E. HURST (Written closure) I have read through the discussion on my paper, and should like to say that I am familiar with the condition mentioned by Mr. Burgess, and confirm that any slight trace of porosity in the surface of Nitri-Castiron is revealed at once in the nitrogen hardening operation by the swelling of the surface at the porous area. In considering the cause of this swelling, I take the view that the effect of hydrogen in the gases must not be neglected. Cylinder liners in Nitri-Castiron are made by the centrifugal process in this country, and this has the effect of minimizing any troubles due to unsoundness.

The contribution of Mr. Harrington to the discussion has interested me considerably, and his description of the precautions necessary in the production of sand castings in Nitri-Castiron reflects exactly our own experience. Considerable assistance can be derived from the use of a flux of cryolite on the surface of the metal.

Mr. Phillips has referred to the wear resistance values quoted in the paper. These, of course, were obtained by direct experiment under carefully controlled comparative conditions, and were fully described in the paper referred to before the Iron & Steel Institute. It is possible that Mr. Phillips' experience of the comparative value of hardened and tempered and nitrogen hardened liners may have been influenced by the quality of the liners used in his trials. His remarks on the virtues of hardened and tempered liners interest me very much, but, unfortunately, they are not supported by any actual figures of wear life, a fact which prevents me from making any useful comments.

Finally, I would repeat that I have been very glad to have the opportunity of describing Nitri-Castiron in this manner to the AMERICAN FOUNDRYMEN'S ASSOCIATION.

X-Ray as an Aid in the Manufacture of Aluminum Castings

BY GEORGE E. STOLL* AND ARTHUR T. RUPPE**, SOUTH BEND, IND.

Abstract

This paper discusses the use of the x-ray as used in connection with the development of casting practices for the production of an airplane carburetor. Variables affecting soundness are listed and the authors discuss the technique required to control these variables. Fairly complete details, are given as to how the x-ray was used in the foundry of the Bendix Corp. to study casting practices. The effect of risers at various points were studied by x-ray examinations. The interpretation in the control of foundry procedure especially as it relates to pin hole trouble is reviewed. The authors further discuss the use of the x-ray as an inspection tool and as an aid in reducing manufacturing costs. The final section is devoted to a discussion of x-ray operation costs.

INTRODUCTION

1. X-ray examination has been used by the Bendix Products Corporation in conjunction with the manufacture of aluminum aircraft carburetors for the past two years and the purpose of this paper is to describe the part x-ray has played in developing and controlling sounder castings and in reducing manufacturing costs. Inasmuch as a number of other papers¹ previously presented to the AMERICAN FOUNDRYMEN'S ASSOCIATION have thoroughly covered the principles of radiography and have described various types of x-ray apparatus, a repetition of this will be omitted. The development of the foundry technique and the use of the x-ray in the manufacture of aircraft carburetors will be used as the basis of the discussion.

*, ** Metallurgist and X-Ray Technician, respectively, Bendix Products Corp.

¹ Confer list of references at end of this paper.

NOTE: This paper was presented before the Non-Ferrous Session of The 41st Annual Convention, Milwaukee, Wis., May 7.

2. The manufacture of aircraft carburetors may be considered by some to be a highly specialized field. The writers, however, believe it to be representative of the modern aluminum foundry industry, since the problems encountered in casting carburetors are much the same as those met when casting other aluminum products.

X-RAY USEFUL IN IMPROVING FOUNDRY PROCEDURE

3. The ability of the x-ray equipment to disclose internal defects in the form of blowholes, shrinkage, porosity and all types of inclusions makes it a decided aid in the development of foundry procedure. The intelligent use of the x-ray enables the foundryman to have a permanent reliable analysis of an experiment almost as soon as guesswork sectioning could be done and in many cases weeks before the casting could be machined and tested.

VARIABLES AFFECTING SOUNDNESS

4. There are many variables that affect the soundness of aluminum castings such as foundry technique, sand condition, pouring technique, type of alloy used, condition of metal and design of casting. These will be discussed briefly to show the importance of having a reliable tool for inspection in developing and controlling the proper foundry procedure.

Foundry Technique

5. Since each individual casting presents different problems, there is no set rule on the proper foundry technique, and here, by technique we mean, gating, placing of risers and chills and their effects on solidification. The ability to apply the proper foundry technique is foundry art and is accomplished by applying past experience and trial procedure.

6. The ideal cooling condition for aluminum castings is a uniform, progressive solidification from points farthest from the feeders toward the feeding areas. In order to obtain this condition, gates, risers, and chills should be properly placed. There are a number of different methods of gating and the method used will be governed by the particular features of a given casting. Care must be used in the placing of chills and risers or they are apt to defeat their purpose by causing unsoundness in other areas.

Sand Conditions

7. In producing sound castings it is important that sand

conditions be controlled. Moisture, permeability and core binders can be the cause of unsound castings.

Alloys

8. The effects of different alloys, metal condition and pouring technique on the soundness of aluminum castings are well known to the foundryman.

Design

9. Since the success or failure of any casting begins with the designer, it is important that he be familiar with the different factors in making aluminum castings. The x-ray examination of a casting gives the designer a clearer picture of some of the foundryman's problems. The x-ray can also be a help to the pattern maker in checking wall thickness and core locations in complicated castings.

Control of Variables

10. It can readily be seen that these variables must be controlled in order to produce sound aluminum castings. The x-ray offers a non-destructive means of seeing and studying the effects of changes in foundry procedure and a reliable inspection tool to control the procedure.

X-RAY TECHNIQUE

11. Little need be said concerning the fundamentals of radiography. X-rays emanating from the tube pass through the casting recording a shadow image on the sensitized film or paper. In taking x-rays of a given casting there are five common variables

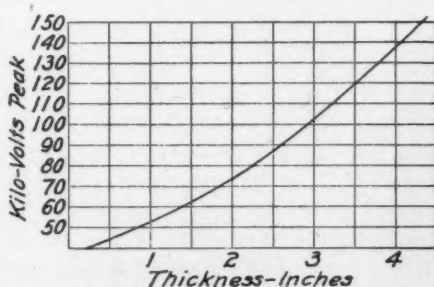


FIG. 1—ALUMINUM TECHNIQUE CURVE FOR X-RAY EXPOSURE, WITH CARDBOARD FILM HOLDER—5 MILLIAMPERES WITH 5-MIN. EXPOSURE—AT 36 IN. FILM TO TARGET DISTANCE.

that can be readily controlled by the technician. These are the voltage, current, time, target to film distance and type of film and screens used.

12. We have found in our practice that it is convenient to maintain amperage and target to film distance constant and obtain the desired results by varying the other factors. For the purpose of illustration we are showing the chart of Fig. 1 which gives variation in voltage needed to penetrate different thicknesses of aluminum, holding the other four variables constant.

APPLICATION OF X-RAY EXAMINATION IN DEVELOPING CARBURETOR CASTING PRACTICE

13. The following discussion, with which are shown photographs and radiographs, presents the development of the foundry

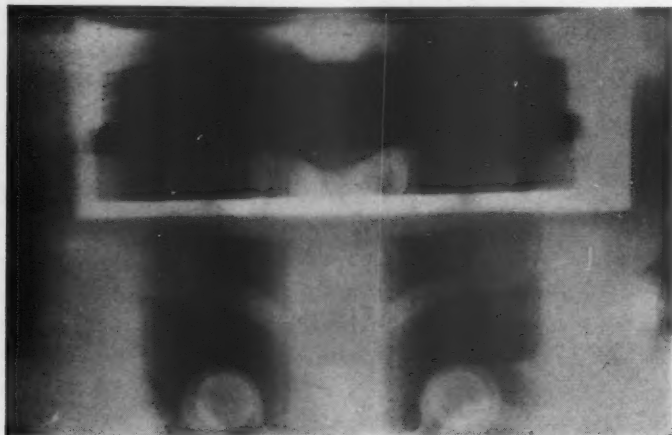


FIG. 2—RADIOGRAPH OF SOUND CASTING.

technique used for one of our carburetor castings. The complete examination of the carburetor casting requires eight different setups, necessitating thirteen radiographs using two and one-quarter square feet of film. The first radiograph taken in the process is through the side of the casting with the cope side down. In this position the metal thickness of the casting varies from one to six inches. A reproduction of one of these "shots," taken with a combination lead and calcium tungstate intensifying screen at 120 kilovolts peak, 5 milliamperes and 5 minutes exposure with a 36 in. film to anode distance, is shown in Fig. 2.

14. The 0.005 in. sheets of lead foil placed next to the film between the tungstate screens absorb some of the secondary radiation from the under side of the casting and hence, reduce the fogging of the film. This "shot" will show up any major defects in the casting but is by no means an absolute check on the soundness of the casting. The rectangular shadow (white outline) evident on the radiograph (Fig. 2) is caused by a 0.005 in. sheet of lead foil placed on the cassette or plate holder directly under the thinnest section of the casting. The metal thickness here is only one inch and without the lead foil this section would be greatly overexposed.



FIG. 3—FILM (A) IN LEAD BACKED ENVELOPE IN POSITION TO RADIOGRAPH BARREL WALLS.

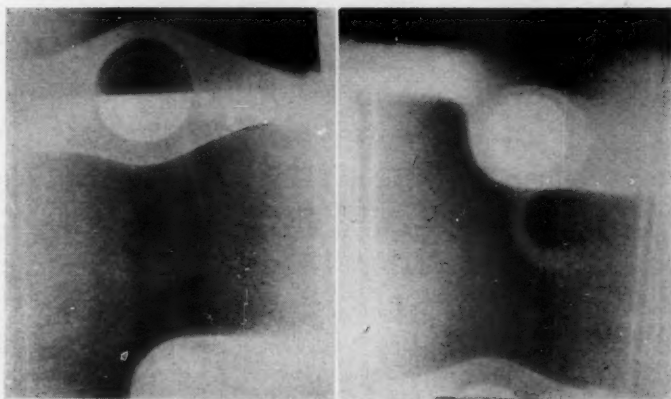


FIG. 4—RADIOGRAPHS TAKEN AS SHOWN IN FIG. 3 OF A DEFECTIVE (LEFT) AND A SOUND BARREL (RIGHT).

Radiographing Thick Castings

15. There are several practical ways in which an object with a considerable range in thickness may be radiographed successfully. One of these, the immersion of the object in a liquid having approximately the same x-ray absorption as the object, has proved satisfactory. A 30 per cent barium chloride solution serves as the immersion medium for some of the smaller carburetor castings.

Checking Barrel Walls

16. In order to check the barrel walls and to be assured of their soundness, six different x-ray set-ups using eleven 4 in. x 5 in. films are necessary. One of these set-ups (Fig. 3) with the accompanying radiographs (Fig. 4) are shown. Fig. 5 illustrates the manner in which the float chamber ends are examined. A radiograph of one of these sections taken at 45 kilovolts peak for one minute with the film in a lead backed envelope is also shown (Fig 6). This x-ray examination gives a complete check on the soundness of the casting.

X-RAY INTERPRETATION IN THE CONTROL OF FOUNDRY PROCEDURE

17. Used intelligently the x-ray can be a decided help in the control of foundry procedure. Otherwise, the x-ray may do more harm than good and be a needless expense. The limitations of the apparatus must be kept in mind and a balance made between the results obtainable and the cost.

18. In many ways the use of the x-ray is similar to that of other laboratory equipment. The technician must work out the techniques to be used and correctly interpret the radiographs. The identification of defects that appear on a radiograph is not always easy. For the most part it is a matter of experience gained by combining radiography and sectioning, and often microscopic examining, by studying synthetic specimens, and by radiographing castings known to be unsound.

Responsibility of the Technician

19. The foundryman well knows the difficulty in producing absolutely sound aluminum castings. It is the responsibility of the technician to determine the seriousness of a defect that might appear in the radiograph of a casting. He must decide whether

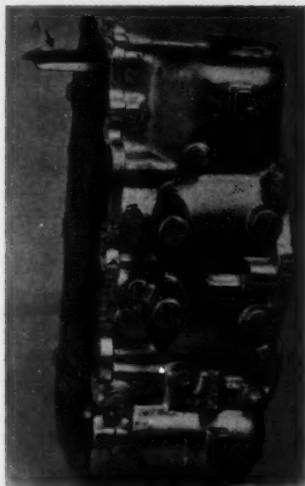


FIG. 5—EXAMINING FLOAT CHAMBER ENDS—(A) SHOWS FILM IN LEAD BACKED ENVELOPE.

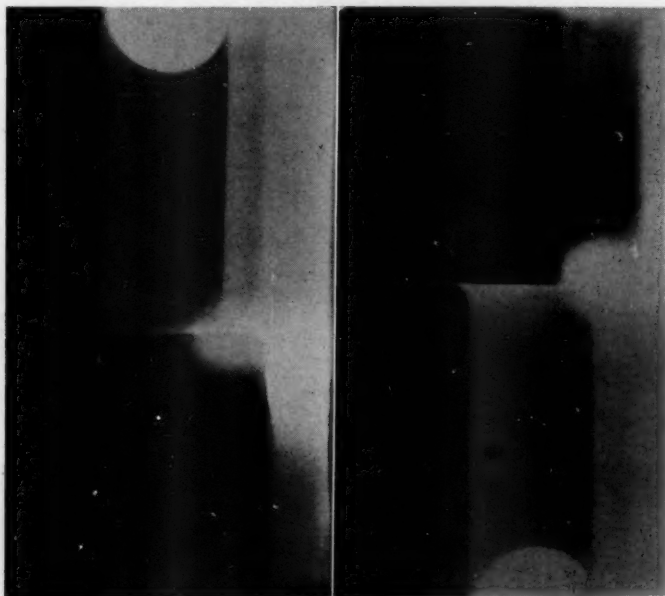


FIG. 6—RADIOGRAPH SHOWING GOOD AND BAD FLOAT CHAMBER ENDS.

or not a blowhole will machine out, whether the porosity is excessive in a particular section of a casting, or if the shrinkage crack will prove detrimental to the finished product. Moreover, in the case of a routine inspection, the technician should be familiar with the casting. He should know the foundry technique, the troublesome areas, and the functioning of the casting. He should be informed of any change in foundry practice and of any new type of trouble appearing in the casting so that the x-ray inspection can be made complete. Co-operation between the foundry

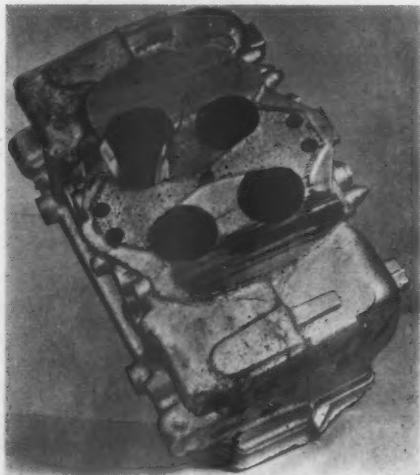


FIG. 7—X-RAY SET-UP TO EXAMINE POROUS CONDITION IN BARREL WALL—CASTING SET AT AN ANGLE TO CHECK AREA BETWEEN FILMS (A) AND BARREL WALL ABOVE. A RADIOGRAPH OF THIS EXAMINATION IS SHOWN IN FIG. 8.

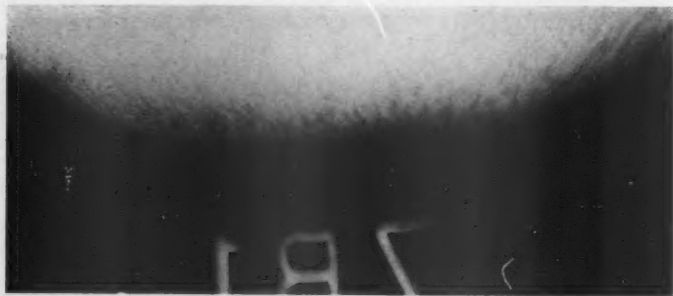


FIG. 8—RADIOGRAPH SHOWING DISTORTED IMAGE OF POROSITY.

dry, the machining inspectors, and the x-ray laboratory is essential if the greatest benefit is to be derived from an x-ray laboratory inspection.

Pin Hole Porosity

20. Of the many types of defects that occur in aluminum alloy castings, pinhole porosity in various forms offers the most difficulty to the x-ray technician. Depending primarily on the tube voltage there is a definite thickness of an aluminum casting that can be satisfactorily radiographed and, also, there is a limit

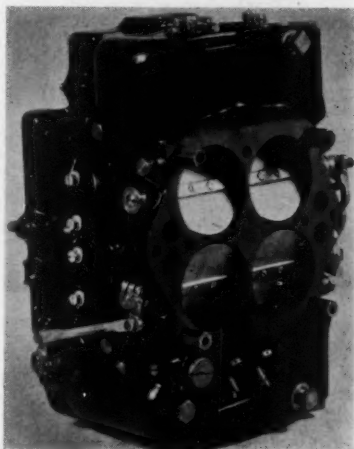


FIG. 9—COMPLETE AIRCRAFT CARBURETOR.

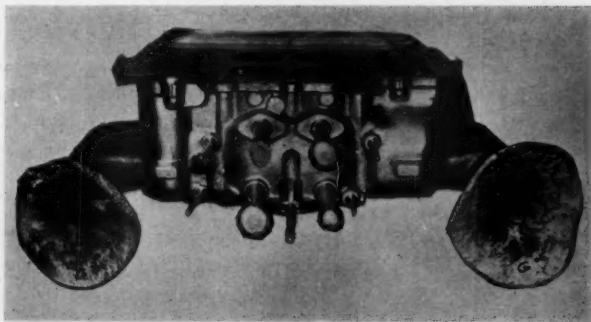


FIG. 10—ORIGINAL METHOD OF GATING CARBURETOR CASTINGS. THE TWO GATES (G) WERE ALSO USED AS FEEDERS.

to the size of defect that can be recorded. In sections up to one inch thick it is possible to detect porosity that is invisible on the surface. However, due to the x-ray set-ups it is not always possible to record and interpret successfully pinhole porosity in complicated castings.

21. At one stage in the development of the foundry technique for the carburetor casting (Fig. 7) pinhole porosity was found in the barrel walls. In some castings this porosity took the form of channel porosity and was the cause of leaky carburetors. Channel porosity, so called because of connecting links between pores, is an extreme case of pinhole porosity caused by a combination of intercrystalline shrinkage and occluded gases. Due to the angle at which the radiograph (Fig. 7) had to be taken and the need of penetrating a half inch of surface metal before reaching the casting proper, a very distorted image of the porosity was obtained (Fig. 8). While it was possible to distinguish between the extreme cases of both types of porosity, a repetition of sectioning, radiographing, and microscopic examining failed to set a definite radiographic standard for a sound casting.

X-Ray as Inspection Tool

22. Aluminum foundrymen are well aware of the fact that unaccounted for defects appear in castings from time to time. The value of the x-ray as an inspection tool lies in detecting these defects before expensive machining operations have been performed. Leakage appearing in carburetor castings on some final test is immediate cause for alarm for several reasons. In the first place, because of the many machining operations, the foundry runs weeks ahead of the machine shop, and at times it is necessary to run castings for stock. Another reason is the fact that a number of leakage tests cannot be made until nearly all of the machining operations have been performed and the loss of a carburetor at this point is a costly one.

23. Once the foundry technique has been established for a particular casting, a 10 per cent x-ray inspection usually offers sufficient control over the foundry output of this casting. Some types of castings do not warrant more than a visual inspection while others have sections which warrant a 100 per cent x-ray inspection. In most cases experience will determine the percentage of castings of a particular type that should be inspected radiographically.

THE X-RAY AS AN AID IN REDUCING MANUFACTURING COST

Machining Costs

24. The aircraft industry, perhaps, demands a more exacting inspection of aluminum castings than do other users. Small imperfections normally overlooked in other aluminum castings are sufficient cause to "scrap" carburetor castings even after expensive machining operations have been completed. A comparison of the assembled carburetor (Fig. 9) with the "green" casting (Fig. 7) will give an idea of the absolute necessity for sound castings.

25. The machining on these carburetors consists of seventy odd operations necessitating fifty set-ups. The time required for the machining and the leakage tests made at various stages of the machining, is seldom under three weeks. Failure on some final inspection due to a leakage is a serious one, not only because of the labor loss but also because of the doubt it throws on the production line. In cases of this kind the x-ray is especially valuable as an inspection tool.

Scrap Losses

26. In the two years that the Bendix Products Corporation has used x-ray examination in conjunction with the manufacture of aircraft carburetors, a considerable reduction in "scrap" loss has been realized. While very little of the credit for the improvement can be attributed directly to the x-ray, indirectly a large part was made possible through the assurance of a complete analysis of any experiment in foundry procedure that might be tried, and of a reliable, non-destructive means of inspecting machined or partially machined castings.

Miscellaneous Savings

27. The intelligent use of the x-ray equipment effects an economy in several other ways. When the foundryman has made some change in an effort to improve his foundry procedure the results can usually be determined quickly and at low cost.

28. An interruption in production is a decided loss. By the use of the x-ray the foundryman can be reasonably sure that only sound castings are sent to be machined. This will help eliminate the possibility of a hold-up in the machining operations.

29. An item of economy rather difficult to compute is the possible results connected with the shipment of a casting, the soundness of which was questionable. The x-ray is another tool

that adds to the confidence of the manufacturer that his castings are sound.

X-RAY OPERATION COST

30. There are a number of factors affecting the cost of radiography. For the most part such items as rent, depreciation of equipment, etc., are constant. However, depending on the size and material of the object being examined, as well as the completeness of the examination, other costs will vary. Labor will of course vary with the time needed for the examination which in

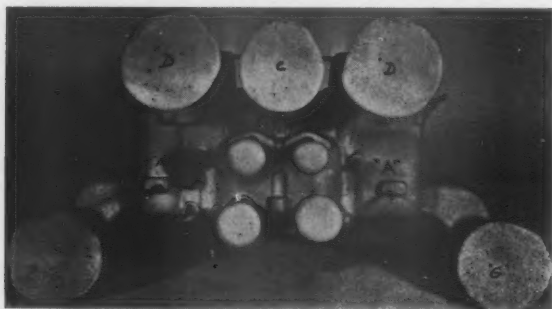


FIG. 11—ADDITION OF THREE FEEDERS (D, C, D.) ELIMINATED DEFECTS IN THE BARREL. SHRINKAGE IN IDLE TUBES (UNDER FLOAT CHAMBER A) STILL EXISTED.

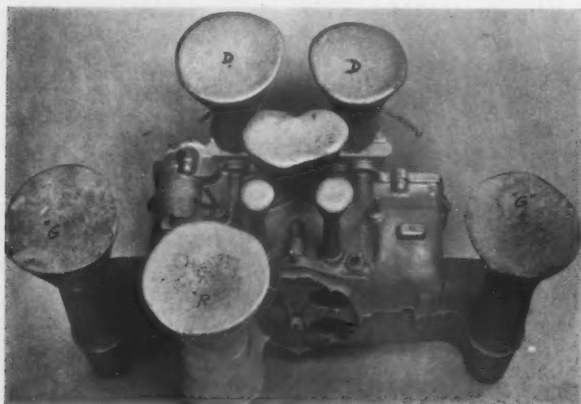


FIG. 12—TWO RISERS (D AND D) IN PLACE OF THE THREE RISERS (D, C AND D OF FIG. 11) WERE FOUND SUFFICIENT TO CORRECT BARREL WALL GAS INCLUSIONS. ADDITION OF HEAVY RISER (R) OVERCAME SHRINKAGE IN ONE IDLE TUBE.

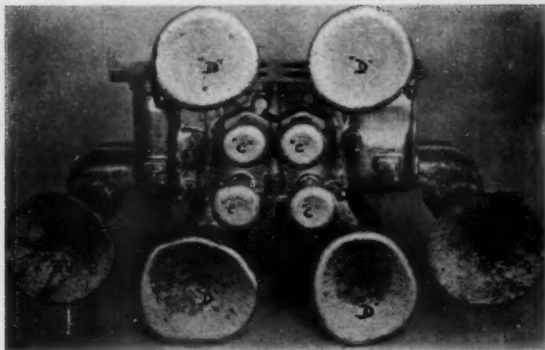


FIG. 13—PRESENT METHOD OF GATING. POURING THROUGH GATES G AND G, WHICH ALSO ACT AS RISERS. VENTS AT C. FOUR RISERS (D) ADDED TO FEED CASTING AND PREVENT POROSITY AND TO PERMIT SCUM IN METAL TO GET OUT OF CASTING.

turn depends upon the particular object being examined. The cost of film or paper will depend on the completeness of the inspection. In many cases of routine x-ray inspection the expense can be lowered by using sensitized x-ray paper, the cost of which is about half that of film.

31. Assuming that 100 square feet of film per month is used, the cost of our x-ray examination amounts to about \$1.75 per square foot. This cost includes the constant items of rent, depreciation, etc., and approximates the variables of labor and material. On this basis the cost of a complete radiographic examination of our large carburetor main body would be approximately \$4.00. However, on production a complete examination is not often necessary and the cost would seldom be over \$1.00.

CONCLUSION

32. Considering the results obtainable, we have come to the conclusion that the x-ray is of decided benefit in the manufacture of complicated aluminum castings. The x-ray is by no means a foundry cure-all but it is a reliable, non-destructive, and when properly used, an economical inspection tool.

ACKNOWLEDGMENT

33. The authors wish to acknowledge the hearty co-operation of J. J. MacQuire, superintendent of the non-ferrous foundry of the Bendix Products corporation. It is also a pleasure to acknowledge the assistance of H. R. Ohlheiser for his helpful criticism.

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DISCUSSION

Presiding: HAROLD J. ROAST, Canadian Bronze Co., Montreal, P. Q., Canada.

MEMBER: Mr. Stoll, do you x-ray every casting?

MR. STOLL: No. With the majority of our castings we find it unnecessary to x-ray them at all, once the foundry technique is established. Some of our complicated castings are given a 100 per cent x-ray inspection at times. The practice depends on the number found defective in a 10 per cent inspection and on the machining reports. Some of our castings have sections which are always giving trouble, a 100 per cent x-ray inspection of these sections is profitable. It all depends on the number of castings, the cost of machining and inspecting and the cost of an x-ray inspection.

MEMBER: The x-raying of castings is probably going to cause us some trouble.

MR. STOLL: But do you know of any other method we can use which will give us a reliable answer as to whether or not a casting is sound? Take a casting similar to this carburetor which cost seventy odd dollars to machine and test. What other method could we use?

MEMBER: But you still do not know the answer if you do not x-ray every casting.

MR. STOLL: You would learn whether your technique has been properly developed. I consider the x-ray the same as the use of the microscope or any other laboratory instrument that we have. You do not study every specimen you are producing in the foundry under the microscope, but when you do have trouble and want to get an idea of the structure, the microscope is very useful. If you want to run a hardness test you might not run it 100 per cent, but you might use it 10 or 15 per cent of the time for inspection purposes. I think that if you once use the x-ray you will find it helpful and that it can be used to advantage. Its greatest value to the foundry is as a developing tool not as an inspection tool.

MEMBER: Mr. Stoll, is this x-ray used by you on any other alloy for pressure castings, that is brass or bronze?

MR. STOLL: We have not used x-ray on any other alloy for pressure castings, but I know it is used quite extensively in steel castings. The size of your equipment would determine whether you could use it. The penetration of the x-ray varies with the size. Aluminum happens to be light and fairly easy to x-ray.

L. W. KEMPF: Messrs. Stoll and Ruppe have, I believe, given us a good example of the intelligent use of the radiograph in connection with the development of castings. I should like to emphasize that word "intelligent". They implied the qualification in their paper where it was said that the radiograph could be quite misleading. We have used the radiograph for developing casting technique in the production of commercial aluminum castings for about ten years. As evidence of our faith in the method, I might state that we started off with one installation in Cleveland; later an installation was put in at Fairfield, and we are just now contemplating a third installation in another foundry. I believe a good all-around radiographic installation for the examination of aluminum castings costs in the neighborhood of \$5,000 at the present time, depending, of course, on the flexibility desired. Our company would not be making such expenditures if it were not convinced of the utility of radiographic examination.

One cannot afford, of course, to radiograph 100 per cent of one's production. Occasionally a job will call for relatively few pieces which perform an important function and then 100 per cent radiographic inspection is justified. There are, however, many jobs which justify the use of radiography for the establishment of the optimum gating and arrangement of risers for the production of a good sound casting. Following the development of the optimum casting technique, it may be desirable, subsequently, to radiograph a certain percentage of the commercial run from day to day. The percentage of the production radiographed may vary from as low as a few tenths of one per cent of the castings—in other words, radiograph one casting not every day but perhaps one a week—to as high as ten per cent of the production. And, as I said, in a few cases involving relatively few parts, very expensive machining operations and the filling of an important function, it may be economical to radiograph 100 per cent of production.

¹ Aluminum Research Laboratories, Aluminum Company of America, Cleveland, Ohio.

Titanium in Cast Iron

By E. R. STARKWEATHER*, NIAGARA FALLS, N. Y.

Summary

This paper is divided into several parts. By way of introduction there is given a brief story of the element titanium and its occurrence. Results of the works of Moldenke, Pheowarsky and Stoughton follow. The various attributes of the element and its effect upon cast-iron follow. This includes its action as a deoxidizer, graphitizer, grain refiner, and also its effect upon the physical properties of iron. The recommended procedure for handling the alloy is also embodied in this section. The treating of electric furnace iron with titanium is then briefly described.

TITANIUM—THE ELEMENT AND ITS OCCURRENCE

1. Titanium was discovered in 1791 by McGregor while investigating a magnetic sand found in Menachan, Cornwall. He named the black sand menachanite (menaccanite) and the newly discovered element in the compound be called menachite. In 1794, while engaged in the study of rutile, Klaproth announced the discovery of a new earth. To the metal of this earth, he gave the name titanium in allusion to the "Titans," the fabled giants of ancient mythology. In 1797, Klaproth found that titanium was identical with the menachite of McGregor, and the name of titanium has been universally accepted.

2. Titanium belongs to Group IV of the Periodic Table, containing also carbon, silicon, zirconium, etc.

3. The first coherent metallic titanium was produced, comparatively recently, by M. A. Hunter (Rensselaer Polytechnic Institute, Troy, N. Y.) by reaction of titanium tetrachloride and sodium in a small heavily reinforced bomb. The substantially pure metal has a steel white color, is hard and brittle when cold, but can be forged at a red heat.

4. Physical characteristics of titanium metal are:

Atomic Weight.....	48
Specific Heat (Mean value 0-100°C.)....	0.1462
Melting Point.....	1795°C.
Specific Gravity.....	4.50
Resistivity.....	3.2 microhms per cm ³
Thermal Expansion (24-153°C.).....	71.4 x 10 ⁻⁷

* Development Engineer, The Titanium Alloy Manufacturing Co.

NOTE: Presented before Gray Iron Session of 41st annual convention, Milwaukee, Wis., May 7, 1937.

5. Titanium is one of the chemical elements which is widely distributed in the earth's crust, ranking ninth among all the elements in abundance. There is more of it than of any of the useful metals, except silicon, aluminum, magnesium and iron. It has a very strong affinity for oxygen and is always found in nature as an oxide.

6. The principal ores of titanium are ilmenite (titanium-iron oxide) and rutile or brookite (practically pure titanium oxide containing small amounts of impurities). Rutile occurs often "in place" and is also found in many sand deposits with ilmenite, zircon, monazite and other minerals.

7. One of the element's chief peculiarities is the readiness with which it combines with nitrogen. It is one of the very few elements which will "burn" in an atmosphere of nitrogen. Its dioxide is one of the most stable compounds known and the expenditure of great energy is required to decompose it. Thus it follows, that when titanium is separated from its oxygen, it will readily recombine with it and energy will be evolved again in the form of heat.

REVIEW OF PUBLISHED INVESTIGATIONS

Findings of Richard Moldenke

8. Among the many eminent men who have contributed so largely to the advancement of cast iron metallurgy, possibly there is no one better known than the late Dr. Richard Moldenke. In his book "The Principles of Iron Founding" may be found the following with respect to titanium and iron:

"This element is found in pig iron very frequently, though in very small percentages, for the difficulty in smelting titaniferous ores of iron in the blast furnace has kept many a rich deposit out of the market. The electric furnace, however, is opening up this field and will eventually see titanium an important factor in pig-iron production. . . .

"As a further proof of the de-oxidizing power of this element, there was noticed in these tests a distinct diminution of the chilling effect, particularly when gray iron was run into iron molds for this purpose. Tests made in connection with the production of car wheels also showed this characteristic, a 1½-in. chill being reduced to 1-in. by the addition of titanium in the ladle. . . .

"When titanium is added to iron in rather higher per-

centages, say 1.00 per cent and upward, there is a remarkable toughening effect noticeable. Indeed the 10 per cent titanium-iron alloy made in the electric furnace has to be sledged apart, the crystalline structure being so tenacious. More than likely the purifying action of titanium, so far as oxygen and nitrogen is concerned, is such that no gas layering or films of iron oxide may remain between the crystals and thus break the continuity of the mass in addition to the weakness due to graphite crystals. . . .

"The following available elements (practically all in form of ferro-alloys) can serve the foundry by removing dissolved iron oxides when added to the molten metal. They are given in the order of their relative efficacy: Titanium, aluminum, manganese and silicon. The others are either too expensive or not sufficiently known."

Conclusions Reached by E. Piwowsky

9. Another well known authority, Piwowsky, has conducted considerable research work on the effect of titanium in cast iron. An abstract of one of his articles¹ is as follows:

"For a long time experiments have been made with the addition of titanium to cast iron, but different and sometimes contradictory results were obtained; therefore, the author took up this work and reached the following conclusions:

- (1) Titanium, like silicon, but to a higher degree, favors the formation of graphite in cast iron; independently of the silicon content, the maximum graphitizing effect is produced by 0.1 per cent titanium.
- (2) Up to that content, the action of titanium on graphite formation hides all other effects on mechanical properties of the iron. With increasing titanium content, the formation of graphite remains constant, but the mechanical properties of iron become appreciably better. Especially the resistance to bending is increased 50 per cent or more.
- (3) As the titanium content increases, the graphite becomes finer, which is advantageous to the iron.
- (4) With titanium additions up to 0.5 per cent, appreci-

¹ "Chemie and Industrie," September, 1924.

able amounts in the metallic state are not incorporated in the iron; the titanium is always present in the form of non-metallic combinations.

- (5) As non-metallic combinations of titanium in cast iron, the nitride and the carbide are easily recognized.
- (6) When the iron is well protected from the action of the air, the titanium is present in it especially in the form of carbide.
- (7) The solubility in acids decreases proportionately with the titanium content.
- (8) The effect of titanium in cast iron is due especially to its purifying action."

Tests Reported by Bradley Stoughton

10. Some years ago Bradley Stoughton² reported as follows in his extensive tests on the effect of titanium on cast iron:

"The combined results of this study, which extended over a period of more than two years, can be briefly summarized in the following three counts: First—Steel and cast iron, in which the titanium is properly proportioned, and which are properly treated, are improved in strength, toughness and durability against wear—such as, for example, the wear of railroad rails, of steel and chilled iron rolls, car wheels, etc.

Second—These improvements seem to be caused, not so much by the direct effect of titanium on the metal, as by its cleansing influence in removing harmful impurities, such as oxygen and oxides, nitrogen, occluded slags, and perhaps also sulphur. It appears also to reduce segregation, which would contribute to the same end.

Third—In order that its effect may be fully realized the treatment of steel or iron with titanium must be correctly performed. There are a few simple, but essential, details to be observed; if they are neglected the best results cannot be expected. This has been taught me, not only by my own experience, but also by the experiments of others.

Summarization of the results obtained by different investigators is shown in Table 1.

² Bradley Stoughton, "The Cleansing Effect of Titanium on Cast Iron," TRANS., A.F.A., vol. 21, 1913, pp. 309-324.

Table 1

SUMMARY OF RESULTS OF INVESTIGATORS

Authority	Used Ferro-titanium	Increased	
		Per Cent Tensile Strength	Per Cent Transverse Strength
Rossi.....	Alloy.....	30 to 50	20 to 25
Schiemann.....	Thermit.....	30 to 50	
Rossi.....	Alloy.....	6 to 30	17 to 23
Goldschmidt.....	Thermit.....	4 to 16	1 to 17
Moldenke.....	Alloy.....		18 (white)
Moldenke.....	Alloy.....		52 (gray)
Guillier.....			49 (mall. iron)
Guillier.....			14 to 30 (gray)
Feise.....	Alloy.....		35
Treuheit.....	Thermit and Alloy.....	No important change†	No important change†
Gale.....	Alloy.....		10 to 20*
Alexander.....	Alloy.....	Increased	Ductility*
Geiger.....	Alloy.....	12 to 26	6 to 10
West.....	Alloy.....		27 to 32
Stoughton.....	Alloy.....		10 to 43

* When treatment was properly performed; otherwise, results different and variable.

† Treatment not made correctly.

These results indicate that it is entirely possible, by correct treatment with ferro-titanium alloy, to increase the strength of cast iron from 30 to 50 per cent. If this can be done part of the time, then it only remains to determine the correct conditions in order to attain equal success all the time.

TITANIUM IN CAST IRON

11. It is to be borne in mind that this section of the paper deals only with ferro-titanium recommended as a spout addition for the cupola. This emphasis is made because there is offered to the metallurgical field, alloys of titanium for radically different purposes.

12. Used for years as a most efficient deoxidizer for steel, one's memory need not be taxed excessively to recall the introduction of the element titanium in gray iron. We are, however, at this time presenting an enumeration of the various effects of foundry titanium upon molten iron.

Effect on Physical Properties

13. Below are to be found the physical improvements due to the addition of one per cent of ferro-titanium to a base iron analyzing 1.77 per cent silicon and 3.63 per cent carbon. The tensile bars were machined from bars 1½-in. in diameter and 14-in. long.

BASE IRON + ONE PER CENT		
BASE IRON	FERRO-TITANIUM	STRENGTH INCREASE
Tensile Strength—	Tensile Strength—	
lb. per sq. in.	lb. per sq. in.	per cent
19700	28900	46.7

14. While the above increase in strength is not typical, it is by no means the only instance of its kind. As another illustration, the transverse bars from the iron *B-1* of Fig. 1 show an increase of 40.7 per cent over the regular base irons of similar analysis. However, in iron *A-1* of Fig. 1, an increase of 19.1 per cent is noted in strength, which is more nearly representative of what should be expected as a result of adding one per cent of the alloy.

Machinability

15. Tests were made by Prof. O. W. Boston, University of Michigan, Ann Arbor, Mich., on the machinability of various irons given below. These were made on his tool dynamometer and applied to broken halves of transverse test bars about $1\frac{1}{4}$ -in. round and 7 to 8-in. long. The results are indicated as dial readings indicating the resistance of the metal to cutting under conditions that were kept uniform for all the tests. Therefore, results reported (Table 2) are comparative only.



FIG. 1.—CHILL TEST RESULTS OF TWO GRADES OF IRON, WITH AND WITHOUT TITANIUM. SPECIMENS *A* AND *A-1* ARE FROM THE SAME BASE IRON AND ANALYZE THE SAME, EXCEPT THAT *A-1* HAS AN ADDITION OF 1 PER CENT FERRO-TITANIUM. LIKEWISE, *B* AND *B-1* ARE IDENTICAL, EXCEPT THAT *B-1* HAS A SIMILAR AMOUNT OF THE FERRO ALLOY.

CHEMICAL AND PHYSICAL RESULTS, THE LATTER BEING THE AVERAGE OF SEVERAL BARS, ARE GIVEN BELOW:

Iron	Transverse Lb.	Brinell No.	Si. %	T. C. %	Ti. %
A	3787	202	2.34	3.38	.....
A-1	4510	229	2.48	3.36	0.132
B	2623	163	2.12	3.58	.....
B-1	3693	187	2.36	3.68	0.172

TRANSVERSE STRENGTH FIGURES ARE ON 12-IN. SUPPORTS AND THE BRINELLS TAKEN ON ARBITRATION BARS. THE *A-1* SPECIMEN INDICATES AN INCREASE IN STRENGTH OF 19.1 PER CENT. LIKEWISE, *B-1* IS 40.7 PER CENT STRONGER. UNETCHED PHOTOMICROGRAPHS OF THE IRON AT 50X ARE SHOWN IN FIG. 2, NUMBERED IN A SIMILAR MANNER.

16. In other words, the nickel-chromium iron (Table 2) was from 9 to 24 per cent more difficult to machine in the lathe test than the titanium-chromium iron. Likewise, the molybdenum iron offered from 40 to 20 per cent more resistance to cutting than did the titanium-chromium iron.

Ability as a Deoxidizer

17. For years, titanium has been employed as a powerful deoxidizer in steel. However, many gray iron foundries are not too

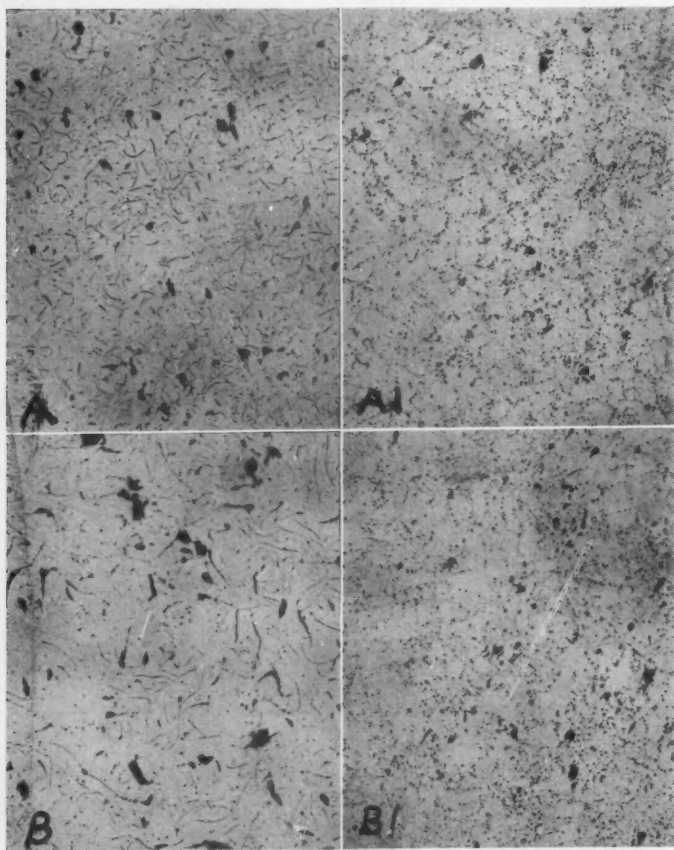


FIG. 2—PHOTOMICROGRAPHS OF IRONS OF FIG. 1—UNETCHED AT 50X.

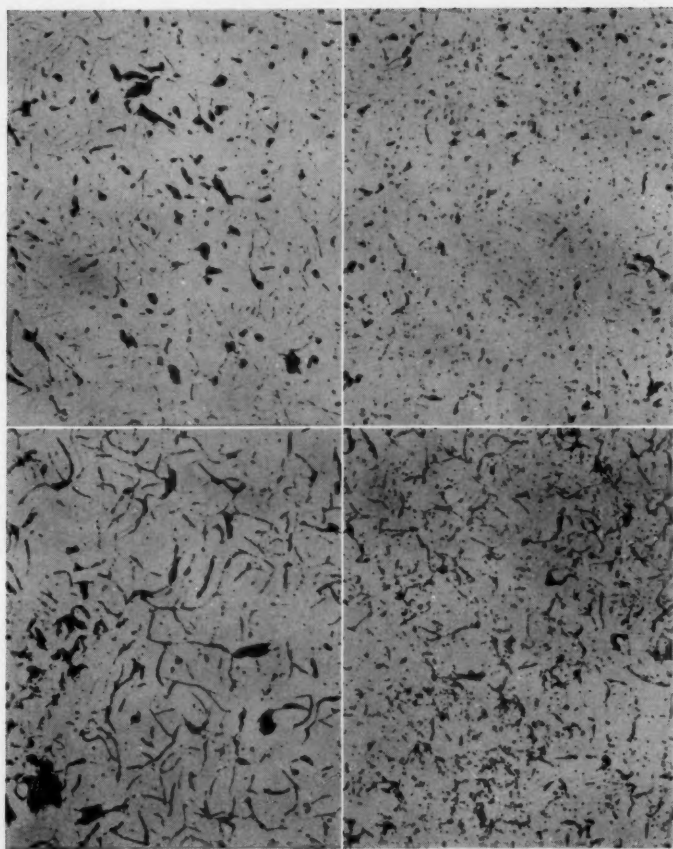


FIG. 3—PHOTOMICROGRAPHS OF IRONS FAIRLY REPRESENTATIVE OF THE IMPROVEMENT UPON THE GRAPHITIC CARBON BROUGHT ABOUT BY INTRODUCTION OF TITANIUM TO BOTH CUPOLA AND ELECTRIC FURNACE IRON. ALL MAGNIFICATIONS ARE 50X.

No.	Grade	Si.	T. C.	Ti.
		%	%	%
A (upper left)	Electric Furnace	2.16	3.46	.....
B (upper right)	Electric Furnace	2.17	3.48	0.147
C (lower left)	Cupola	2.33	3.31	.....
D (lower right)	Cupola	2.43	3.35	0.108

Table 2
MACHINABILITY OF TITANIUM CAST IRON

	Iron No. 1	Iron No. 2	Iron No. 3
Silicon, per cent.....	2.21	2.10	2.19
Graphite Carbon, per cent.....	2.71	2.71	2.77
Combined Carbon, per cent.....	0.72	0.70	0.62
Total Carbon, per cent.....	3.43	3.41	3.39
Ferro Titanium, per cent.....	1.00	0.0	0.0
Nickel, per cent.....	0.0	1.35	0.0
Molybdenum, per cent.....	0.0	0.0	.46
Chromium, per cent.....	0.54	0.62	0.0
Tensile Strength, lb. per sq. in.....	38,700	38,640	38,960
Transverse Strength, lb.....	5,004	4,789	5,093
Brinell Hardness No.....	207	207	202
Comparative resistance to cutting:			
Lathe test 0.00313-in. feed.....	22.5	23.0	27.0
Lathe test 0.00694-in. feed.....	37.5	41.0	39.0
Drill Test, Torque.....	19.0	20.5	20.5
Drill Test, Thrust.....	880	900	900

well informed as to its possibility in their own field. Its role as a cleanser and purifier of the metal is easily observed after the ladle is full. A greater surface accumulation of a slag-like material is at once apparent and the molder is forcibly reminded that the treated iron has had a greater amount of impurities removed. Too much stress cannot be laid upon the necessity of carefully skimming in such instances.

18. The ability of the alloy to act as a deoxidizer and scavenger of the molten metal has been mentioned in the preceding pages by Moldenke, Piwowsky and Stoughton.

Graphitizing Effect

19. Graphitizing effect is illustrated by Figs. 4 and 5. Fig. 4 shows the graphitizing action of 1 per cent and 2 per cent of the ferro-titanium on a very hard, low-silicon, "white" iron. As may be noted, the base iron as shown on the left is solid chill. Fig. 5 shows the effects upon the "chill" of various alloys, alone, and in combination. The base iron in all six is the same.

Analysis of the Alloy

20. The analysis of the ferro-titanium recommended as a spout addition to cast iron is as follows:

	Per Cent
Titanium	17 to 22
Silicon	17 to 22
Aluminum	0.40 Max.
Carbon	0.50 Max.
Iron	Remainder

Method of Handling

21. No difficulty should be encountered in handling this material which comes in the $\frac{1}{8}$ -in. form which melts at about 2370°F . The recommended procedure is to add it at the tap hole. Upon tapping out, the alloy is allowed to fall upon the stream of molten iron and flow down the spout into the ladle. Obviously, the ideal rate is one which will find the last of the alloy going into the iron just before the ladle is full. When this operation is completed the ladle will have an abnormal surface accumulation of impurities. As mentioned previously, very careful skimming is absolutely essential.

22. May we emphatically state that ferro-titanium is not to be regarded as a "cure all" inasmuch as this is asking too much of any alloy. Each has its place in the metallurgical field and judgment and experience alone should make the decision.

Titanium in Electric Furnace Cast Iron

23. All of the above applies to ferro-titanium used as a spout addition in cupola melted cast iron. However, another grade of ferro-titanium which works admirably in the electric furnace is offered to the foundry industry. The cost of this is only about

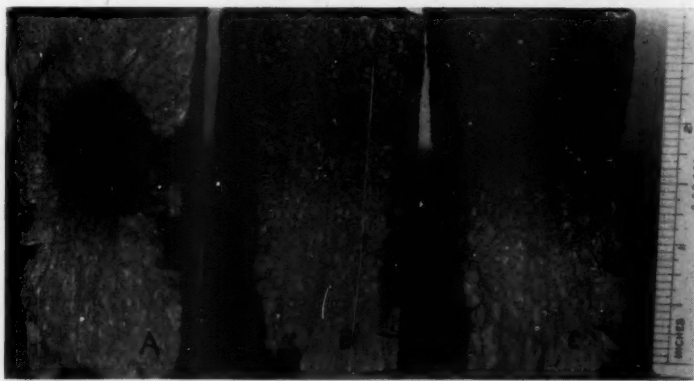


FIG. 4—THREE CHILL TESTS TAKEN IN A LARGE PENNSYLVANIA FOUNDRY SPECIALIZING IN CHILLED IRON ROLLS POURED FROM IRON MELTED IN AN AIR FURNACE. READING LEFT TO RIGHT:

A—BASE IRON—SOLID CHILL.

B—BASE IRON WITH AN ADDITION OF 1 PER CENT FERRO-TITANIUM.

C—BASE IRON WITH AN ADDITION OF 2 PER CENT FERRO-TITANIUM.

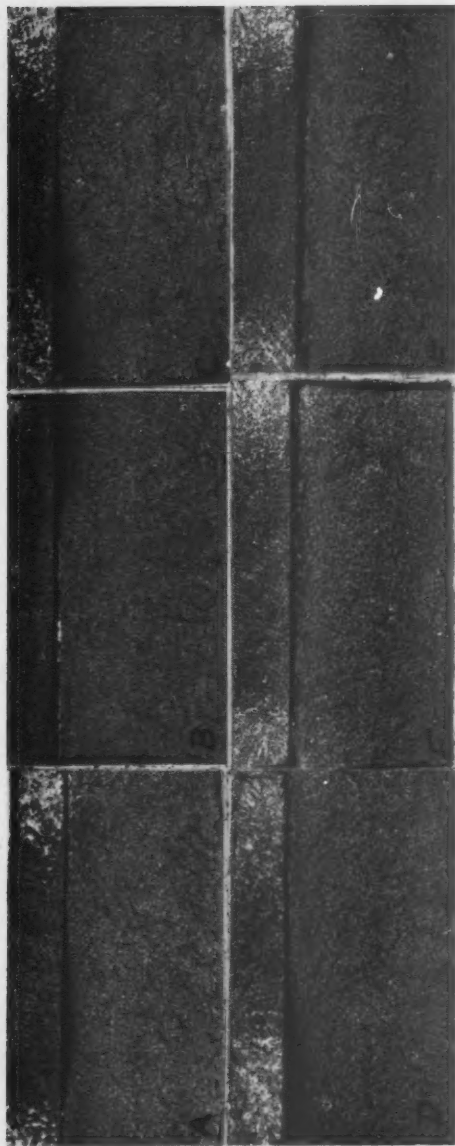


FIG. 5—SIX SPECIMENS ALL POURED FROM THE SAME BASE IRON CONTAINING 3.17 PER CENT CARBON AND 2.24 PER CENT SILICON. A IS THE UNREMOVED IRON, B 1 PER CENT TITANIUM, C 1 PER CENT TITANIUM AND 0.42 PER CENT MANGANESE, D 1 PER CENT TITANIUM AND 0.74 PER CENT CHROMIUM, E 1 PER CENT TITANIUM AND 0.74 PER CENT CHROMIUM AND 1.27 PER CENT NICKEL, F THERE WAS ADDED 0.72 PER CENT CHROMIUM AND 1.27 PER CENT NICKEL.

PHYSICAL TEST RESULTS

No.	Alloy Addition	Transverse Deflection Lb.	Deflection In.	Tensile Lb. per sq. in.	Brinell No.	Alloy Addition	No.	Transverse Deflection Lb.	Deflection In.	Tensile Lb. per sq. in.	Brinell No.
A	None	4400	0.125	35,840	196	D	0.72 per cent Cr.	4390	.107	43,000	223
B	1 per cent Ferro-Titanium	4512	.134	39,900	207	E	1 per cent Ferro-Titanium	4380	.112	46,680	223
C	0.42 per cent Mo.	4362	.115	44,300	223	F	1.27 per cent Ni.	4672	.106	42,940	223

one-third that of the cupola alloy and hence it is an unusually inexpensive alloy to use.

24. A representative analysis of this is given below:

	Per Cent
Titanium	16.65
Carbon	7.52
Graphite	3.75
Silicon	2.75
Aluminum	1.63
Chromium	0.17
Manganese	0.14
Iron	Remainder

25. The above material, although possessing a higher melting point than the cupola ferro-titanium, dissolves quite readily in the electric furnace. In the event that it is used in conjunction with other alloys, the titanium should always be added last. The pronounced refinement of the graphitic carbon brought about by this alloy is illustrated in Fig. 3.

ACKNOWLEDGMENTS

26. The author wishes to acknowledge the helpful cooperation given by Messrs. T. C. Mellon, general superintendent, and Lynn Reynolds, metallurgist, Worthington Pump & Machinery Corporation, Buffalo, N. Y. Had it not been for two of the author's colleagues, Messrs. Wilbur G. Wellings, chief development engineer, and George F. Comstock, metallurgist, this paper would doubtless never have been written. The former offered many timely and valuable suggestions, while the latter not only supervised all the metallurgical tests contained herein, but also provided much valuable information from his very complete records.

DISCUSSION

Presiding: J. W. BOLTON, Lunkenheimer Co., Cincinnati, Ohio.

C. O. BURGESS:¹ Does Mr. Starkweather have any explanation for the fact that, although titanium appears to materially reduce the chill appreciably on the specimens, the titanium-treated specimens show a somewhat higher hardness remote from the chills? That is, in the mass of the casting, not, of course, at the chilled edge, but in the body of the casting,

¹ Metallurgist, Union Carbide and Carbon Co., New York, N. Y.

although you have a reduction in chill depth, the body of the casting appears to be slightly higher in Brinell.

GEO. F. COMSTOCK:² My opinion is that the reason is that the graphite flakes are finer. The iron is, in other words, closer grained when titanium is added. I think that refinement of the graphite structure accounts for the increase in Brinell hardness.

CHAIRMAN BOLTON: What about the structure of the matrix?

MR. COMSTOCK: The structure of the matrix with titanium often shows more ferrite than without and yet we get the higher Brinell in spite of that.

CHAIRMAN BOLTON: What is the action of titanium on ferrite or pure iron, for example? What does the iron-titanium diagram look like in terms of hardness?

MR. COMSTOCK: Titanium in solution with ferrite will harden it, but with carbon present, as it is in cast iron, there is practically no titanium in solution with the free ferrite; it is present there as a carbide or nitride.

CHAIRMAN BOLTON: That seems to be an anomaly, doesn't it? The fact that it acts as a graphitizer and actually produces free ferrite and also forms carbide.

MR. COMSTOCK: Yes, it is rather strange, but the explanation that has been given for that is that the graphitizing effect is due to its deoxidization. Any deoxidizer is apt to cause graphitization of iron. The carbide of titanium is practically insoluble in the iron, so that it does not affect the ground mass as other carbides do, such as chromium-carbide or manganese-carbide, which are much more soluble in the austenite.

CHAIRMAN BOLTON: I got the impression, from Boyle's paper, that vacuum melting where you take all of the gases out, including the oxides, tended to speed up graphitization?

May I ask, Mr. Starkweather, whether you are including a table in your paper giving the relative heats of formation of the various oxides?

MR. STARKWEATHER: Complying with the excellent suggestion of Chairman Bolton, may we offer the following:

To make this comparison accurately, we must first decide just how the various affinities for oxygen are to be measured. The best measure of this property is generally considered to be the heat of formation of the oxide of the element in question since according to a law of nature, oxygen in a mixture of metals will tend to form that oxide which will result in the greatest evolution of energy in the form of heat; or in other words, elements whose oxides have a high heat of formation will deoxidize those whose oxides have a lower heat of formation. There are differences of opinion, however, as to the terms in which the values to be compared should be expressed. Taking the molecular heats of formation from a handbook³ is one way of making the comparison; Hibbard has compared⁴ the calories generated when one kilogram of each element is burned; and

² Metallurgist, Titanium Alloy Manufacturing Co., Niagara Falls, N. Y.

³ "Handbook of Chemistry and Physics," Hodgman and Lange, 14 ed.

⁴ Hibbard, "Calorific Value of Steel Making Elements," IRON AGE, Jan. 11, 1923, p. 143.

Parsons gives⁵ a similar tabulation of the heats of formation of oxides in calories per gram-atom of oxygen. These values are compared, for the oxides that may be formed in the deoxidation of steel, in Table 3.

Table 3

Compound	Molecular Heat of Formation (Hodgman and Lange)	Calorific Power per Kgm of Element (Hibbard)	Heat of Formation, Cal. per Gm.-Atom of Oxygen (Parsons)	Melting Point of Oxide °F.
Iron Oxide, FeO.....	65,700	1173	...	2585
Manganese Oxide, MnO.	90,800	(1988 Mn ₂ O ₄)	90.8	3000
Calcium Oxide, CaO....	151,900	3740	151.9	4600
Zirconia, ZrO ₂	177,500	....	...	4500
Silica, SiO ₂	191,000	7595	95.5	3150
Titanium Oxide, TiO ₂ ..	218,400	4540	109.2	2800
Vanadium Oxide, V ₂ O ₅ ..	310,500	2000?	...	1220
Phosphorus Oxide, P ₂ O ₅ ..	365,200	5892	73.0	1480
Alumina, Al ₂ O ₃	380,000	7270	130.8	3700

It is evident from this table that although the agreement between the three sources of data is not exceptionally close, titanium stands high in each series.

MR. F. HARRINGTON:⁶ If I understood Mr. Starkweather correctly, there is an equivalent amount of silicon with the titanium addition so that for each one per cent of titanium addition of the alloy, you would get a similar amount of silicon in the actual mix. It would seem to me that it might have been well to include with the comparison an iron that contained an equivalent amount of silicon added in the form of a late furnace or ladle addition of ferro-silicon to see the effect of ferro-silicon alone.

MR. STARKWEATHER: You mean, were you to add, say, 20 or 25 points of silicon to a base iron, what the difference would be in the physical properties, with a corresponding amount of titanium? Silicon, of course, is, as is titanium, a graphitizer, but silicon tends to reduce the physical properties of your metal, whereas titanium improves them.

A. L. BOEGEHOLD:⁷ I might cite the data that was given in the paper on Wednesday showing the effect of late additions of silicon to a mixture of cast iron that was melted in an induction furnace, and the increase in tensile properties in that case due to a late addition of silicon was considerably more than the amount of tensile strength increase that has been obtained here with the titanium addition. Now, it is just a question of whether the increase in physical properties here has been obtained from the silicon addition or from the titanium addition. I think that point certainly ought to be cleared up.

DR. J. T. MACKENZIE:⁸ Wouldn't it be true that if the titanium suppressed the secondary graphitization, that the silicon would harden the

⁵ Parsons, "Phosphorus in Red Brass," THE FOUNDRY, Aug. 1932, p. 16.

⁶ Metallurgist, Hunt-Spiller Manufacturing Co., Boston, Mass.

⁷ Metallurgist, General Motors Corp., Detroit, Mich.

⁸ Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.

matrix, the ferrite especially, and even though you had small graphite, it would be harder and stronger?

MR. STARKWEATHER: As I understand it on that point, the reason why you get improved physical properties by incorporating a certain percentage of titanium in the iron is the fact that you have a much finer graphite. That was shown by several slides there. The refinement of the graphite will give you better physical properties.

MR. COMSTOCK: We have tried using ferro-silicon in place of this ferro-titanium containing silicon and have not obtained the same results in the same grade of iron. We have not obtained the same grain refinement that we get with titanium. But the chief answer to these objections that have been raised regarding silicon seems to me to be that the same results can be obtained in electric furnace iron by using a high carbon ferro-titanium, where the iron is melted in such a way that the high carbon ferro-titanium will dissolve, which means in the electric furnace practice. That kind of ferro-titanium has a low silicon content, so that the effects of titanium additions with that practice are obtained without the simultaneous action of any appreciable amount of silicon.

MR. STARKWEATHER: Substantiating the previous speaker, may I offer actual figures from just such an experiment?

The results of the tests* are as follows:

	Corrected Transverse Strength, Lb.
Untreated iron.....	{ 3560 3100
1 per cent ferro-silicon added.....	{ 3080 2550
1 per cent ferro-titanium added.....	{ 3590 3550
2 per cent ferro-silicon added.....	{ 2700 3180
2 per cent ferro-titanium added.....	{ 4240 4150

The pot to which the last addition was made came from a different cupola-tap from the others, so that although the increase in strength was 26 per cent, the result is not strictly comparable. The other values show quite definitely that the average strength was decreased by ferro-silicon, but increased slightly by the ferro-titanium.

* Comstock, G. F., "Titanium in Cast Iron," IRON AGE, June 1, 1933.

Firestone as a Refractory

By HARRY RAYNER*, DETROIT, MICHIGAN

1. Firestone, a silica rock deposited in the early stages of the earth's history, was formed by the ceaseless washing of the seas. Rocks composed of various materials, such as silica and alumina, were subjected to the eroding action of the waves, forming layers or sheets of varying thicknesses and of uniform composition. These deposits were cemented and hardened under great pressure and by chemical agencies for ages, and have been found to be so uniform and situated to advantage that they were adapted to commercial use¹.

2. Firestone, formed naturally as above due to a combination of its peculiar granular structure and chemical analysis, coupled with colloidal silica bond, has great resistance to combined heat and abrasion agencies, which makes it adaptable as a refractory.

GRADE OF STONE USED—PROPERTIES

3. The grade of stone suitable for refractory purposes is known as "split rock". This has a stratified or laminated structure with a cleavage in straight and parallel lines. The lines of the grain are clearly visible and the split follows these lines quite accurately. The binding material is amorphous (colloidal) silica. Firestone is practically free from contamination with lime or other alkali which would act as a fluxing agent, thus aiding its refractory properties.

4. A typical chemical analysis of firestone is as follows:

	<i>Per Cent</i>
Silica (SiO_2)	93.13
Alumina (Al_2O_3)	3.86
Ferric Oxide (Fe_2O_3)	0.11
Ferrous Oxide (FeO)	0.54
Magnesium Oxide (MgO)	0.25
Calcium Oxide (CaO)	0.10
Loss on ignition	1.43

* Foundry Metallurgist, Chrysler Corp., Detroit, Mich.

¹ Geological Survey of Ohio. Fourth Series Bulletin No. 18. United States Geological Survey, Bulletin No. 818.

NOTE: This paper was presented at the session on Refractories at the A.F.A. Milwaukee Convention, May 6, 1937.

5. Physical Properties:

Crushing strength: 8,000 to 10,000 lb. per sq. in.

Modulus of rupture: 675 to 850 lb. Taken on blocks 2 in. square in cross section, 4 in. long, with distance between supports 3 in.

Fusion point: 3000° F. (Seger Cone No. 32) It does not soften until very close to fusion point.

Weight per cu. ft.: 133 to 140 lb.

6. The expansion curve is fairly uniform on the first heating of firestone up to about 1100° F. A more rapid expansion takes place at this point and up to its fusion point. Allowance for this property has to be made when the material is subjected to heat as a refractory, and this will be explained later in this paper.

SIZES

7. Firestone is quarried by cross cutting with a channeling machine which is self propelled, after which it is drilled and broken out with wedges. It is then lifted and either broken down by drilling, or is sent to saw mills, planers, lathes, etc., to be further fabricated by hand or machinery.

8. In a number of uses of firestone for linings, the stone is sawed to exact sizes but it also can be split accurately enough for the purpose. Some users prefer to have stone in large pieces and split it themselves. Splitting the rock is a very simple operation and can be learned readily by any unskilled workman. Split rock linings of convenient size, 18 in. x 12 in. x 6 in., to be handled by one man are typical, as illustrated in Fig. 1. The stone will split readily and with straight parallel surfaces. Other sizes can be procured as desired by splitting in like manner to suit requirements. This adaptability is of great advantage, as a little practice will enable any unskilled workman to break out slabs at very little cost. Slabs can be procured in this way to use as patching or resurfacing over the cupola blocks, being replaced as fast as they burn out, thus always protecting the back lining.

9. When the refractory properties of firestone first began to be realized, hand cut cupola blocks were made from this material. Due to certain characteristics of the stone, some of which have been

mentioned, a definite procedure for lining the melting zone of cupolas has been developed.

10. Only the melting zone is lined with firestone, as this material will not stand abrasion before it has been vitrified or sintered, and, therefore, would not stand the constant wear caused by the material in the charges above the melting zone scraping against it.

11. Standard sizes can be obtained or any size desired. The melting zone is lined with such pieces, installed with due allowance for expansion on the preliminary heating. This expansion is a favorable property if the blocks are put in correctly and can be disastrous if not done right. Care must be taken in the preliminary lining to see that the grain of the stone, exposed to the fire or interior of the cupola, runs vertically or horizontally, and not parallel with the lining. (Fig. 2). When patching, the slabs can be parallel but must be firmly secured so that the expansion which takes place at first will not push the patch out. As firestone holds up well under service, an advantage in its use is a more positive and fixed diameter, maintained in the melting zone, making for more exact control of the melting. Due to less erosion, there is much less bridging experienced than with the more commonly used refractories.



FIG. 1—METHOD OF SPLITTING ROCK FOR CUPOLA LINING

STORING

12. Unseasoned firestone should be stored in a dry place. Firestone has a tendency to "season" when stored after having been taken from the quarry. It will "air dry" in a few days in a reasonably dry atmosphere if kept under cover. If it is not feasible to store inside, firestone is to be put in the cupola as received from the quarry but must be dried out with a very slow fire, and the stone not allowed to reach a temperature higher than 200° F. The writer recommends that the stone be dried in a suitable oven such as a core drying oven and the stone kept at a temperature not to exceed 200° F. for four or five hours. We may be a little too

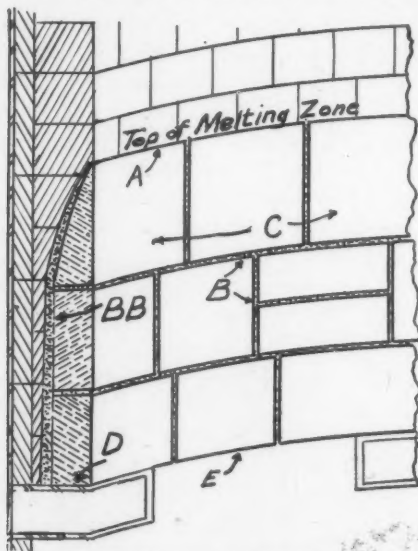


FIG. 2—METHOD OF INSERTING REFRACTORY IN CUPOLA

particular in regard to the necessity for drying for we have lined up cupolas with unseasoned stone, run off 24 hour 350 ton heats with no bad results, but knowing the characteristics of the stone, still hesitate to use it without air or oven drying.

USE IN MELTING ZONE

13. When starting to use firestone, clean out the melting zone entirely back to the outer ring of insulating brick which is usually left in the cupola when relining. If desired, stone may be

put right back to the shell, but we would recommend that at least a split for insulation and a backing be used.

14. A good bearing should be secured over the tuyeres (Fig. 3) so that the lining which is quite heavy, will rest on a firm foundation being well built when completed.

15. A stiff mortar is made from a mixture of ground firestone and a medium plastic fire clay. This mortar is applied over the insulating brick (or shell) to a depth of about 1 in. This is applied as the lining goes up and acts as a cushion between the expanding stone and shell thus taking care of the expansion.

16. For the joints, we use a mixture of 40 per cent clay and 60 per cent ground firestone. The joints should be kept $\frac{1}{4}$ to $\frac{1}{2}$ in. wide to allow for expansion of the stone which compresses the joints and sets up the whole lining firmly with tight joints, a condition conducive to long life for the refractory. The stone should be laid with grain horizontal if the cupola is larger than 60 in. inside diameter. In smaller cupolas the stone should be laid on edge with the grain vertical and showing the edges. This provides more joints around the circle and makes a better circle in the small diameters. The grain shows distinctly on four surfaces and it is easy to determine the proper setting. Half sizes are used in small cupolas and full 12 in. sizes in larger ones.

HEAT ACTION ON STONE

17. After a few trials and a little experience on the part of the cupola repairman, the operations are gradually improved and adjusted to one's own shop conditions. The stone can be split into so many shapes that only a few of the fundamental points need be followed such as proper exposure of grain surface and taking care of the expansion. It should be noted that if after a short heat the cupola is picked out and the stone appears soft, succeeding heats will take care of this by vitrifying the surface. This also applies to a soft appearance of the stone back of the material that has been chipped out. Lining in front of this with blocks or patches is the proper procedure and gives long and satisfactory service for when the heat gets back to this soft stone, it sinters it and forms a continuous monolithic lining.

18. Firestone works satisfactorily in the well of the cupola, using the same procedure as one would with fire brick except to take care of the expansion.

19. Firestone slag holes (Fig. 3) can be used but care must

be taken not to break the block or use a rod in the hole until the surface has been sintered or glazed by hot slag. The blocks will not stand hammering until the heat has hardened them. If allowed to sinter, they will last a long time.

TEST HEAT RESULTS

20. In a test heat made at the Chrysler foundry under the writer's supervision, the following results were obtained. The melting zone was cleaned out to the shell which measured 90 in. A one inch backing of ground firestone and fire clay in the proportion of 60 per cent stone and 40 per cent clay was used. A medium plastic Ohio clay with over 3000° F. fusion point was used. This

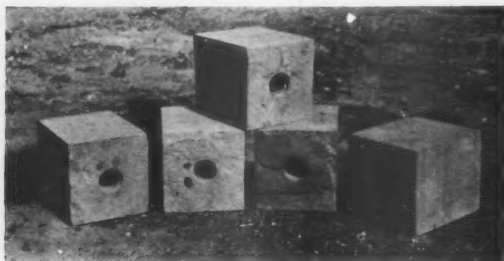


FIG. 3—SLAG HOLES

was made up into a stiff mortar. Four inch blocks of firestone were placed against the one inch backing, and stiff fire clay and silica sand mortar was used between all joints which were kept at about $\frac{1}{2}$ in. thick. The 4 in. row was carried up to a predetermined height of 42 in. established by observation of previous heats in the same cupola. Then against the 4 in. thick row, a row of 7 in. blocks were built in like manner with $\frac{1}{2}$ in. of stiff fire clay and silica sand mortar. The firestone for this heat was dried over night in a stationary core oven with a temperature close to 200° F. The stone was placed on skids and conveniently run into the oven with an electric truck. After the melting zone was lined as above, the cupola was "brought in" in the usual manner. The fire was lighted two hours before the blast was put on. The blast pressure was 16 to 18 oz. The heat was run continuously for 24 hours.

21. At the end of this time, 350 tons had been melted, the cupola had not bridged as much as with a 12-hour run with our previous lining. This lining was worn back for only 6 in. or an

average of 1 in. for every four hours. We have found from further experience that the erosion is much greater during the first part of the heat. The last few hours of a 30-hour heat showed very little more wear than that experienced in a 24-hour heat. We experienced a little trouble with our bottom sand in a few of the first long heats. Our bottom doors became red but this tendency was overcome by a more refractory and better rammed bottom. Now we experience no trouble up to 30 hours.

22. Heats formerly ran 12 hours and in 12 hours consumed 6 to 8 in. of the brick lining. Twenty to 24-hour heats invariably caused the lining to become so thin as to cause red spots to show on the shell and at times the lining burned right through the shell into the wind box, having consumed the entire 12 in. of the brick lining. A 16-hour heat with the cupola lined with brick would consume about 10 in. of the lining.

Our experience with this stone enabled us to show the following savings:

1. Cut the consumption of refractories in half.
2. Eliminated eight to ten hours labor of five men on each cupola as we relined only once in 24 hours as against twice with brick.
3. Eliminated one coke bed of about 2 tons of coke.
4. Eliminated the waste of 2500 lb. of bottom sand.
5. Obtained better service out of slag hole and tap hole blocks as they are now replaced every 24 hours instead of every 12 hours.
6. Melted 30 tons more of iron in 24 hours than possible before due to less bridging.
7. Eliminated the draining and "breaking in" of one cupola with its attending hazards.
8. Savings in dollars and cents by eliminating labor and material was over \$100.00 per day.

LADLES

23. Having had such marked success with the use of firestone in the cupola, we decided to try it in the "bull" or crane ladles and the results were even more gratifying. We found that a $1\frac{1}{4}$ to $1\frac{1}{2}$ in. split stone lining lasted more than three times as long as the previous lining. We have not been able, however, to replace the brick in the bottoms of the ladles due to spalling action

of the stone on the bottoms. We expect to do further experimental work with the idea of using stone on the bottoms as well as on the sides.

OTHER USES

24. Cupola refractories are uppermost in the foundryman's mind, particularly the gray iron founder, so we have paid more attention to this phase of the use of firestone than the importance of this material in other fields of refractories warrants. There are many more uses for this material, and we will review these briefly.

25. Firestone is used extensively in Pugh type or car ladles and mixers in carrying iron from the blast furnace, as a lining for soaking pits, and in lining bessemer converters with extra large and thick pieces for the nose and shoulder.

26. Ground firestone, previously mentioned, is excellent for use in furnace bottom. We use the waste chips from the blocks to advantage. The outstanding characteristic which distinguishes it from other sands is its ability to sinter well and to a considerable depth. For use in bottoms, the sand must be well dried.

27. Foundries can now run cupola heats of 48 hours with better results than at previously running 24 hours. Some foundries have run heats as long as 72 hours. It takes no great stretch of the imagination to visualize foundries water cooling their cupolas and running all week. It is the writer's belief that better refractories and improved practices are paving the way for this and many other at present unthought of developments in furnace practice.

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